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WATER REQUIREMENTS OF CROPS IN INDIA

STORAGE

BY

J. WALTER LEATHER, Ph.D., F.I.C., F.C.S

Imperial Agricultural Chemist

AGRICULTURAL RESEARCH INSTITUTE, PUSA

PUBLISHED FOR

THE IMPERIAL DEPARTMENT OF AGRICULTURE IN INDIA

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INTRODUCTION.

IN Chapter XI of their report, the Indian Irrigation Commission, 1901-03, remark: "In the course of our investigations we have been struck with the small amount of attention which appears to have been given by the Departments of Agriculture and Public Works to matters connected with the application of water to cultivated crops. At present most of the information which can be had on these points has to be taken from papers published by the Agricultural Bureau in America." It is indeed hardly necessary to dilate on the general importance of the subject in India where an efficient water-supply is, over at least very large areas, probably of greater importance than any other condition which appertains to its agriculture.

The subject of the water-supply to crops may, apart from rainfall or questions of irrigation systems, be conveniently subdivided under six heads :—

(1) the moistness of a soil for the purposes of germination and initial growth ;

(2) the total quantity of water required by a crop ;

(3) the period of growth during which a crop requires most water ;

(4) the amount of water which is contained in a soil ;

(5) the proportion of this which is available to crops ;

(6) the effect on *the development of a crop* of varying proportions of water in any specified soil.

The information contained in this Memoir relates to the *second* and *third* of these subjects.

The vegetable physiologist has devoted attention largely to the organs of plants which chiefly control transpiration. He has compared the process with the relative abundance of the stomata, has estimated the relative activity in this respect of the upper and lower side of the leaf, the activity of the parenchyme, the function of hairs and the like. In such investigations the water transpired is commonly referred to the leaf area, or to a unit area of leaf, or equal parts of a plant have been employed and the quantities of water transpired in equal periods of time have been compared. But for the end which we have in view, namely, an estimate of the water required by crops, such investigations can only have an indirect value. Experiments have also been made on the effects of light of different refrangibility, of temperature, and of humidity. Whilst the first of these has no direct bearing on our subject, the second and third are important, but a knowledge of their influence during the whole growing period is required rather than at individual times. Indeed, experiments have been so commonly made for short periods of time and so frequently with parts of plants of non-agricultural interest, rather than with the more important field crops, that much of what has been published on transpiration of water becomes of little direct use to us. It will be well to emphasise the limits of the subject we are to deal with. It is simply "How much water is transpired by our several field crops?" and "during what period does the crop require the principal portion of this water?" Several experimenters have estimated the former, whilst as to the latter question, although deductions may be made from published data, attention does not appear to have been directed to it specially.

As regards the total quantity of water involved, it is to be anticipated that a large plant or crop will transpire more water than a small one of the same kind. Consequently it becomes essential to adopt a mode of expressing our quantities which will make them applicable to all general cases.

Those who have dealt with the subject which we have in hand, have uniformly referred *the water transpired to the weight of dry plant produced*, and have expressed the relation between these two quantities as a *Ratio*, namely, the parts by weight of water transpired per 1 part of dry plant substance produced. This is the *Transpiration Ratio.* Thus, if the transpiration ratio of wheat were stated to be 500, it would imply that for each pound or ton of wheat crop grown, including the grain, chaff and straw, (but not the root) 500lbs. or tons of water would be transpired. It is then a simple matter to calculate the quantity per acre ; for instance, say a wheat crop weighed 4,000lbs. per acre, and the transpiration ratio were 450, then the weight of water transpired per acre would be $4,000 \times 450 = 1,800,000$lbs. or $\frac{1,800,000}{2,240} =$ 804 tons or, since an acre of water 1″ deep weighs (approximately) 227,000lbs. $\frac{1,800,000}{227,000} = 7{\cdot}95$ inches. This is the simplest mode of stating the information and is adopted in this publication in so far as the first of our two subjects is concerned.

Reference may now briefly be made to the work of others. The transpiration ratio of field crops has been determined at four Agricultural Stations, namely, at Rothamsted (1848) by Lawes, at Dhame (1867—72) by Hellriegel, at Munich (1876) by Wollny, and at Wisconsin (1891-92) by King.

Their results may be suitably summarised thus : —

STATEMENT I.

	Lawes Ratio.*	Hellriegel Ratio.†	Wollny Ratio.‡	King Ratio.§
Wheat	247	338	...	...
Barley	257	...	774	393
Oats	...	376	665	522
Rye	...	353	...	...
Maize	...	...	233	310
Beans	209	282	...	...
Peas	259	273	416	477
Clover	269	310	...	453
Buckwheat	...	363	646	...
Colza	...	329	912	...

* Jour. Horticultural Soc. V (1850).

† Grundlagen des Ackerbaues, p. 622, et seq.

‡ Einfluss der Pflanzendecke und Beschattung auf die physikalische Eigenschaften und die Fruchtharkeit des Bodens, p. 125.

§ Rep. Wisconsin Expt. Stn., 1894, p. 248

From the papers which these authors published it appears that the amount of water transpired is very large, that it is greatest during the period of rapid leaf development and until the fruit is formed after which it declines, and that it is affected by temperature, atmospheric humidity and the supply of plant-food.

It is evident, however, that, inasmuch as Indian climatic conditions are so widely different from those of the Agricultural Stations mentioned, the above transpiration ratios would in any case require careful check by experiments made in India before they could be employed with any confidence here. And this is the more desirable because of the very considerable differences which occur in the values of the published ratios.

The question as to whether plants transpire more, or less, water in the tropics than in Europe, has indeed formed the subject of a number of experiments and discussions since 1892. Haberlandt, from experiments made at Buitenzorg in Java and at Graz in Holland, concluded that the transpiration is much less in the "moist-warm" climate of West Java than in middle Europe. Against this opinion Gitlay, Burgerstein, Holtermann and others have quoted experiments which contradict such a conclusion. It seems that all the observations related to amounts of water transpired during short intervals of time such as a couple of hours, and were for the most part referred to the area of leaf surface involved; also that many of the experiments were made with parts of plants. The limitation of the work has been fully recognised by Burgerstein who says (page 173) "dass es nicht angeht, die in absentia solis für ein paar Tage ermittelte transpiration abgeschnittener Zweige oder Blätter von ein paar Pflanzenarten für die tatsächliche Jahresleistung eines ganzen Vegetations gebietes zu substituieren." (*Trans.:* that it is not legitimate to substitute for the actual yearly requirement of a whole vegetable region, the transpiration of isolated twigs or leaves of a couple of plant varieties, which has been ascertained in the absence of direct sunlight during a couple of days). It is obvious that the factors which control the water requirements of any particular crop are so numerous and the value of each so

difficult to determine with even approximate precision, that it seems unreasonable to deduce it for one country from observations made in another of entirely different climate. The data which we have obtained at Pusa do in fact show that the total water requirement of some of the crops grown during the moist period of the S. W. monsoon is distinctly smaller than those grown during the cold weather, and thus support in part Haberlandt's argument, but it is equally certain that the corresponding requirements of other crops grown at the same period are much larger. The nature of the plant is an important factor.

For several years records of the amount of water which plants, specimens of our field crops, transpire throughout their period of growth have been maintained at Pusa by means of "pot-cultures," and comparison of these data showed that they were so regular that, apart from other evidence, they might properly be accepted as a means of calculating the total quantity of water required. It will probably be most convenient to the reader if the subject-matter is divided as follows :—

(*a*) method employed ;

(*b*) data obtained ;

(*c*) examination of the data with a view to establishing the effect of various influencing factors.

Method Employed.

Pot-cultures.—The Pot-culture House at this Institute and its adjuncts have been described in Memoir No. 3 (Chem. Series) and it will therefore suffice if details of the method followed are given.

The cultivation jars.—These are glazed stoneware and have the following dimensions :—

Size.	Diameter, inches.	Depth, inches.	Soil capacity, kilos. (Approx.)
A	9	12	14
B	9	16	22
C	9	22	29
D	12	16	31
E	12	22	50

Filling the jar.—The soil is always damped before being packed into the jar, because experience has shown that the water subsequently added becomes distributed much more uniformly if this procedure is adopted than if the soil is packed in air-dry. As regards the degree of moistness, discretion has to be used, for soils vary within wide limits in the amount of water required to make them moist; but, roughly speaking, sufficient water is carefully worked into the soil to make it just adhere together when pressed in the hand, without running the risk of it "puddling." Some soils are packed into the jars by pressing with the fist, others such as the Black cotton soil, are best only shaken into the jar. After filling the damped soil into the jar, water is added in quantities of about half a litre per day until the desired quantity has been introduced.

Mode of adding water.—In these experiments the water was always added by means of unglazed earthenware cylinders of about 2″ diameter and from 6″ to 10″ deep, provided with small holes in the bottom and lower part of the sides. These cylinders are fixed in position in the centre of the soil when filling the jar, so that the upper edge coincides approximately with that of the jar. By this means the surface soil remains loose, friable, and nearly air-dry, and cracking is thus avoided. The direct loss of water from the soil surface is at the same time much reduced. Experiments which have been made to test this latter point have shown that the loss of water from this cause has been reduced to about one-third by the use of these cylinders of what it would have been had the water been added at the surface of the soil.

In some soils, however, experience has shown that the surface becomes air-dry to such a degree by this method of watering, that the germination of the seed and the initial development of the young plant are interfered with, and consequently in such cases water is added at the surface until the plant is established, after which water is best supplied by the cylinders. The question naturally arose as to whether the root development occurred principally in the immediate neighbour-

hood of the cylinder. It was suspected that this might take place just where the water was introduced, but examination of the root systems has shown that the principal development is at the bottom of the jar, or at least below the cylinder and fully as much at the sides of the jar as near the cylinder. No particular accumulation of root has been found about these cylinders.

The water employed.—Clean well water has been used throughout.

Addition of fertilizers.—Wherever fertilizers are used, these are added either in the dry state to the air-dry soil before it is damped for filling, or the substance is dissolved in the water used for damping the soil.

Sowing seed.—From ten to twenty seeds are usually sown at regular space intervals immediately the jars are filled with soil.

Thinning.—After the seed has germinated and the plants fairly established, they are reduced in number and again further reduced a few days later to a small number, such as three or four; these are allowed to mature. This "thinning out" of the plants has been always (except in the first and second seasons) completed before the amount of water transpired became of material consequence. In the first and second seasons when this was not done, the thinned out plants were weighed and allowance for the water they had transpired was made in the final calculations.

Weighing.—The jars have been weighed *every morning* throughout the whole period of growth.

In each case the weight of jar, soil and water are known and these together form the "standard weight"; where the weight of the plant is so considerable that this should be included in order to avoid any serious error, an estimate of it is made and the "standard weight" increased accordingly. Usually this is unnecessary.

After recording the weight of the jar, the difference between this and the standard weight gives the weight of water transpired by the plant and lost by the soil during the preceding 24 hours, and this quantity of water is added so that the standard moistness of the soil is reinstated.

Control jars of soil.—The water lost from a jar of soil with plants growing in it is necessarily the sum of that transpired by the plants and that lost directly by evaporation from the soil. Our object is to estimate the former quantity.

Most experimenters on the subject of transpiration have employed *covered* jars in order to reduce the direct loss from the soil to a minimum. Thus Lawes placed glass plates, having holes in them for the plants to grow through, over the soil and cemented them to the edge of the jar. Hellriegel also in his later work employed close covers.

This device has not been employed at Pusa. In our experiments over 100 cultivations have been maintained at one time, and it would not only have increased the cost of the apparatus very considerably to provide such covers, but would in practice have been all but impossible of application at the time of filling jars and sowing. A much more serious matter is, however, the fact that by covering up the surface of the soil, normal aeration becomes suspended ; and although our information regarding the value to a growing crop, of aeration of agricultural land is most imperfect, the suspension of this process would throw a doubt on the value of the work. Finally, it was ascertained that the loss of water from the soil is very regular, and is so small in comparison with that transpired by a heavy crop, that sufficiently exact information as to its magnitude may be ascertained by maintaining jars of the same soil containing the same proportion of water as that employed in the series of cultures. The error only assumes material proportions in the case of small stunted plants, and, as will become evident, this is of small consequence.

The method adopted is briefly this. For each experiment (except during the first season) a jar of the same size containing the same soil has been maintained at the same degree of moistness throughout the period of growth and the daily loss of water registered against the total loss from the other jars of the series. For the experiments with a number of crops grown in the same soil *four* such jars (two of which were manured) were used.

Now it is not to be expected that the soil of a series of jars, even though all are filled alike with the same soil and maintained with the same proportion of water, will evaporate exactly the same amount of water, and the records of the four jars mentioned provide an index of this difference. For example, during the growing period of the Juar last year, June 15th to November 11th, these four jars lost 9·93, 10·68, 13·03, and 14·11 kilos respectively. (It may be mentioned here that these differences are not in any way due to the presence of manure in the soil.) The arithmetical mean of these is assumed to be the amount of water which has evaporated directly from the soil during the experiment. This method of estimating the factor is naturally not perfect but is more free from defects than any other and yields results which, at least for all well grown plants, are subject to an experimental error of not more than 5%. The corresponding error for poorly developed ones is larger, but the correctness of the transpiration ratio is not of great consequence in such cases.

Protection from rain.—All jars are brought under cover in wet weather, as also at night.

Harvesting.—As the plants matured, they were cut off close to the root, air-dried, the seed finally separated, the whole weighed, and the remaining moisture determined. The weight of the material was then reduced to the dry state. In a few cases, (guar) cyamopsis psoralioides, and (arhar) cajanus indicus, some of the pods ripened before the remainder of the plant ; in these the pods were removed as they ripened, so as to avoid losing them.

Effect of the sun's heat on the jars.—One of the criticisms which have been made on the pot-culture method for the determination of the transpiration ratio is that, since the jars are exposed to the direct rays of the sun, and the temperature of the soil is in consequence exposed to greater fluctuations than would occur in the field, a serious error is probable.

In order to test this question certain jars of maize in 1907 and of wheat in 1907-08 were maintained in large boxes surrounded with 5″—7″ saw-dust throughout the period of growth : with which exception, however, the conditions

corresponded with other jars fully exposed. The results are summarised thus :—

STATEMENT II.

Protection.	Water in soil.	Manure used.	Dry crop, grms.	Water transpired, kilos.	Ratio.
			Maize. 1907.		
Exposed to sun	20%	*Nil*	11·26	6 81	606
Protected	.	,, ...	8·2	5·15	630
Exposed to sun	...	Nitrate and phosphate ..	35·82	13·7	382
Protected	...	,, ,,	40·95	17·30	428
			Wheat 1907-08.		
Exposed to sun	20%	*Nil*	8 58	9·72	1133
Protected	...	,, ...	8·33	8·45	1014
Exposed to sun	...	Rape cake and phosphate	38·49	27·91	725
Protected	...	,, ,,	43·22	35·97	832

An examination of these data show that the exposure of the jars to the sun had no influence on the ratio.

Diurnal variation of water content in soil.—Although it was arranged to maintain a certain degree of moisture in the soil, it is obvious that as transpiration proceeds during the day, a decrease must occur in this proportion of water, and it is of interest to note how much this was. As in all such calculations, it is preferable to take maximum figures. Accordingly we may select instances from the largest and the most vigorous plants growing in the smallest jars. Such for example were the manured peas ; these transpired about 1 kilo of water per day for a short time. The soil contained (at 20%) 2·72 kilos of water, so that during the day the amount of water decreased to about 1·7 kilos when the percentage in the soil would be about $12\frac{1}{2}$. This is naturally a great variation, but the experiments of the cold weather 1906-07 and the monsoon 1907 have shown that the transpiration ratio is not affected, within certain limits, by the amount of water in the soil, and those limits were not exceeded. But in most cases the diurnal percentage variation was considerably less than this, and in the large jars of soil it was only nominal.

PART II.

Details of Pot-cultures.

Inasmuch as a large part of the records obtained by pot-cultures lend themselves to tabular statement, this method has been here adopted and the chief data are so exhibited in the following pages. In most cases a chart is added showing the daily weight of water lost throughout the growing period together with its relation to the atmospheric humidity. Illustrations of most of the plants themselves are likewise added.

Apart from data, there are however several other matters which require explanation.

General synopsis of the experiments.—In the first season, the cold weather 1906-07, wheat was grown in Pusa soil in two sizes of jars. In each of these sets of jars three different proportions of water in the soil were maintained, and the jars of each of these sub-divisions were differently manured. It was intended to grow lucerne in two others, but the first seed used did not germinate, and in order to avoid losing a season, new lucerne was sown in only one set of the jars, and Cicer arietinum (Gram) in the other. The lucerne grew well at first, but failed later; the gram was more or less diseased. In the following monsoon period maize was selected for the experiments and was grown in Pusa soil. Here three sizes of jar were employed, three different proportions of water were maintained in each set and the soil of each sub-division was differently manured. An examination of the data thus obtained during two seasons seemed to indicate one or two general conclusions. The depth or quantity of soil employed, affects the size of the plant, and seemed to have a moderate influence on the transpiration ratio: the effect of different proportions of water in the soil was not appreciable. On the other hand, the effect of a fertilizer containing nitrate and phosphate had in both seasons a very marked influence on the ratio. Another marked difference was noticed between the transpiration ratio for wheat and maize respectively, the former being materially larger than the latter. During the next season, the cold weather

of 1907-08, it was decided to check the results obtained with wheat. For this purpose it was grown in Pusa soil in two sizes of jar; in each set two different proportions of moisture in the soil were maintained, and the soil of each subdivision was differently manured; in this case, however, oil-cake was used instead of calcium nitrate or calcium cyanamide. These experiments fully substantiated the first in all important respects, and it was decided to enlarge the scope of the experiments particularly in two respects; firstly, to employ a variety of soils as different from one another as possible, in which the same plant would be grown; secondly, to employ half a dozen of the chief field crops, all of which would be grown in the same soil. The former list included, in addition to the highly calcareous Pusa soil, a black cotton soil, a soil containing an unusually high proportion of organic matter and two rather sandy soils. Details regarding this section of the investigation will be the subject of a future communication. The ratios obtained with maize during the monsoon were quite regular and indicated that the nature of the soil has either no influence or at most only a nominal influence on the transpiration ratio. The cold weather ratios, obtained with wheat, proved irregular in some respects and make it necessary to repeat this section of the work.

For the second section of the work a number of different crops were grown in Pusa soil. The plants employed were seven during the monsoon of 1908, namely, zea mais (maize), oryza sativa (rice), andropogon sorghum (the big millet juar), the two small millets, eleucine coracana (murwa, ragi) and paspalum scrobiculatum (kodo) and two pulses, cajanus indicus (arhar, tur) and cyamopsis psoralioides (guar). Similarly during the succeeding cold weather, 1908-09, seven other plants were included, namely, wheat, oats, barley, linseed, B. campestris (sarson), peas and cicer arietinum (gram). Regarding the general growth of the plants, the following brief remarks may be made:—In nearly all cases germination was regular. Most plants develop very well in the small jars (size A), but maize forms a conspicuous exception and does not form cobs

properly in these. As will be seen by reference to the data, this fact seems to have affected the transpiration ratio in only a moderate degree. The large millet juar, though it did better than maize, was not a really good specimen. But all the other plants, even the large pulse, arhar, have grown to great perfection. The latter grew 8 feet high and wheat about 4 feet high in the manured soil in these small jars.

Duplication of jars.—During the first three seasons no experiment was duplicated, dependence being placed on a single jar in each case, but the results obtained did in fact substantiate one another indirectly because several of the conditions, such as proportion of water in the soil, proved to exert no very great influence on the transpiration ratio. In the following seasons, the monsoon 1908 and the cold weather 1908-09, only one proportion of moisture was adopted in any one case, and duplication of jars was more necessary. An examination of the data show that such duplication is an advantage, but the number of cases where a serious difference in the result occurs is only very small. For the purpose of a ready comparison of the data, the statements have been arranged according to the nature of the plant, in the following order :—

Cold weather season	Wheat	
	Barley	
	Oats	
	Linseed	
	Sarson	
	Peas	
	Gram	
Monsoon crops...	Maize	
	Juar	
	Rice	
	Marwa	
	Kodo	
	Arhar	
	Guar	

The data for wheat which has been grown during three seasons are arranged chronologically ; and the same has been adopted for maize which has been grown during two seasons.

The numbering of the plates and charts in this Memoir is such that the same number is given to the statement, the plate, and the chart of any one crop, and consequently some plate and chart numbers are absent from the Series; for example, there are no plates or charts corresponding to statements I and II; there is no chart No. III; there is no plate No. IX, etc.

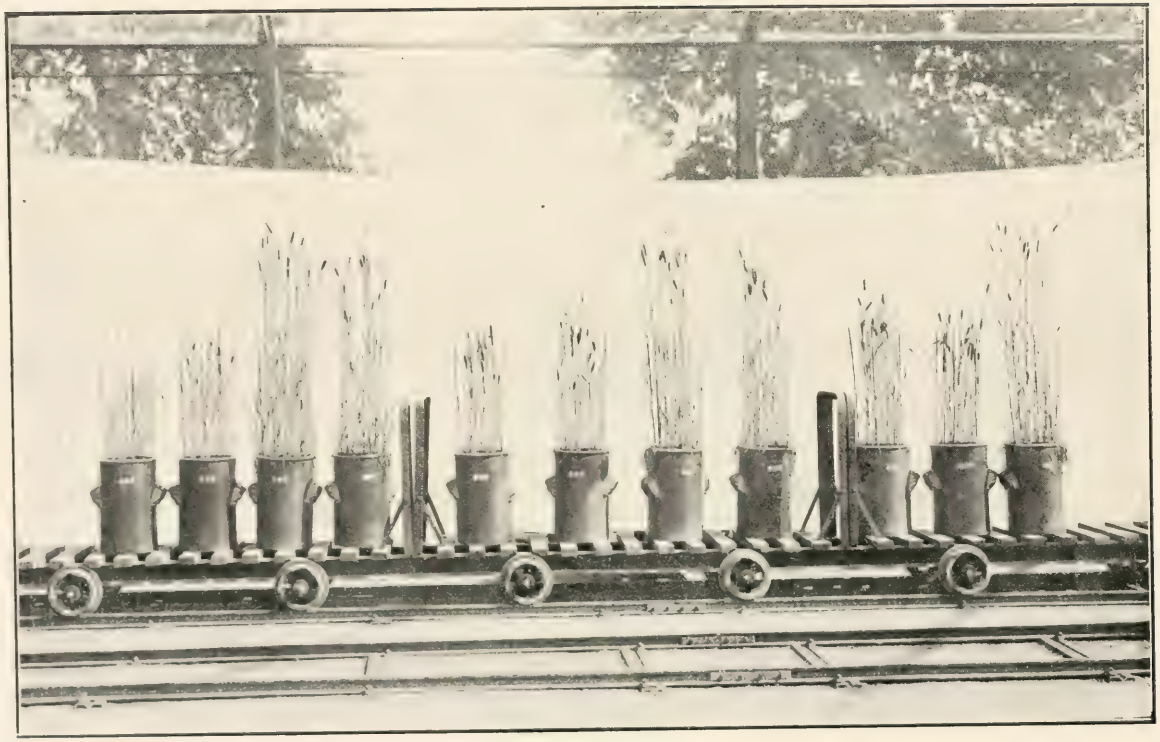
STATEMENT III.

Triticum sat. (Wheat) 1906-07.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired Kilos.	Ratio.
101	A=9″ diam. ×12″ deep.	About 15 kilos. of Pusa soil.	10	Nil	23-10 06	22-4-07	2·5	9·6	8·65	900
102			10	N	23-10-06	22-4-07	1·8	11·3	11·83	1,050
103			10	N+P	23-10-06	5-4-07	13·0	41·0	22·26	543
104			10	N+P+K	23-10-06	5-4-07	12·4	43·2	22·72	527
105			15	Nil	23-10-06	22-4-07	1·9	8·4	5·48	653
106			15	N	23-10 06	22-4-07	2·1	13·5	12 72	944
107			15	N+P	23 10 06	5-4-07	13·0	40·5	21·85	540
108			15	N+P+K	23-10 06	5-4-07	11·9	39·9	20·76	515
109			20	Nil	23-10-06	22-4-07	3·7	15·6	12 90	829
110			20	N	23 10 06	22-4-07	3 3	8·1	18·07	1,000
111			20	N+P	23-10 06	5-4-07	15·1	53·3	30·63	574
112			20	N+P+K	23-10 06	5-4-07	12·0	44 7	26 05	583
C=Ca $(NO_3)_2$=·005 grm. N; P=superposphate = ·01 grm. soluble P_2O_5 and K=K_2SO_4=·005 grm. K_2SO_4 per 100 grm. soil.										
401	B=9″ diam. × 16″ deep.	About 22 kilos. of Pusa soil.	10	Nil	24-10 06	22-4 07	3 9	16·2	15 25	941
402			10	N	24-10 06	22-4 07	2·1	14·9	12·41	806
403			10	N+P	24-10-06	5-4-07	23·3	72 3	42·91	593
404			10	N+P+K	24-10-06	5-4-07	15·2	50·2	30·82	614
405			15	Nil	24-10-06	22-4 07	4·8	22·0	23·32	1060
406			15	N	24-10-06	22-4 07	4·8	22·5	18·83	837
407			15	N+P	24-10 06	5-4 07	24·4	79·1	39·88	504
408			15	N+P+K	24-10-06	5-4-07	18·1	54·7	33·05	604
409			20	Nil	24-10-06	22-4-07	6·8	29·5	28·17	955
410			20	N	24-10-06	22-4 07	5·3	21·5	18·60	865
411			20	N+P	24-10-06	5-4-07	28·4	86·9	44 62	515

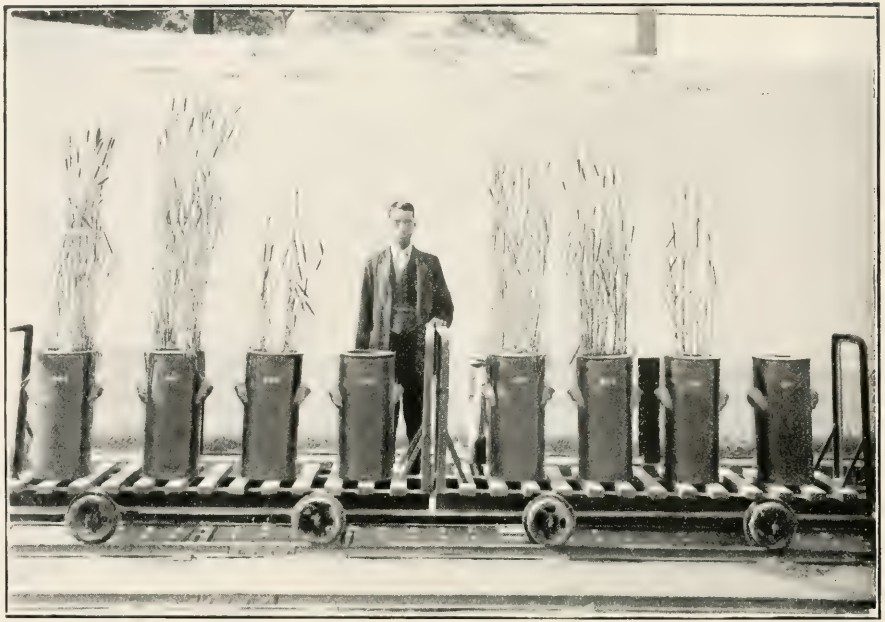
N = Ca CN_2 = ·005 grm. N per 100 grms. soil; P = superphosphate = ·01 grm. soluble P_2O_5
K = K_2SO_4 = ·005 grm. K_2O per 100 grms. soil.

PLATE III.



WHEAT, 1906-7.

PLATE IV.



WHEAT, 1907-8.

504, 508. Oil Cake and Superphosphate.
503, 507. Oil Cake.
502, 506. No manure.

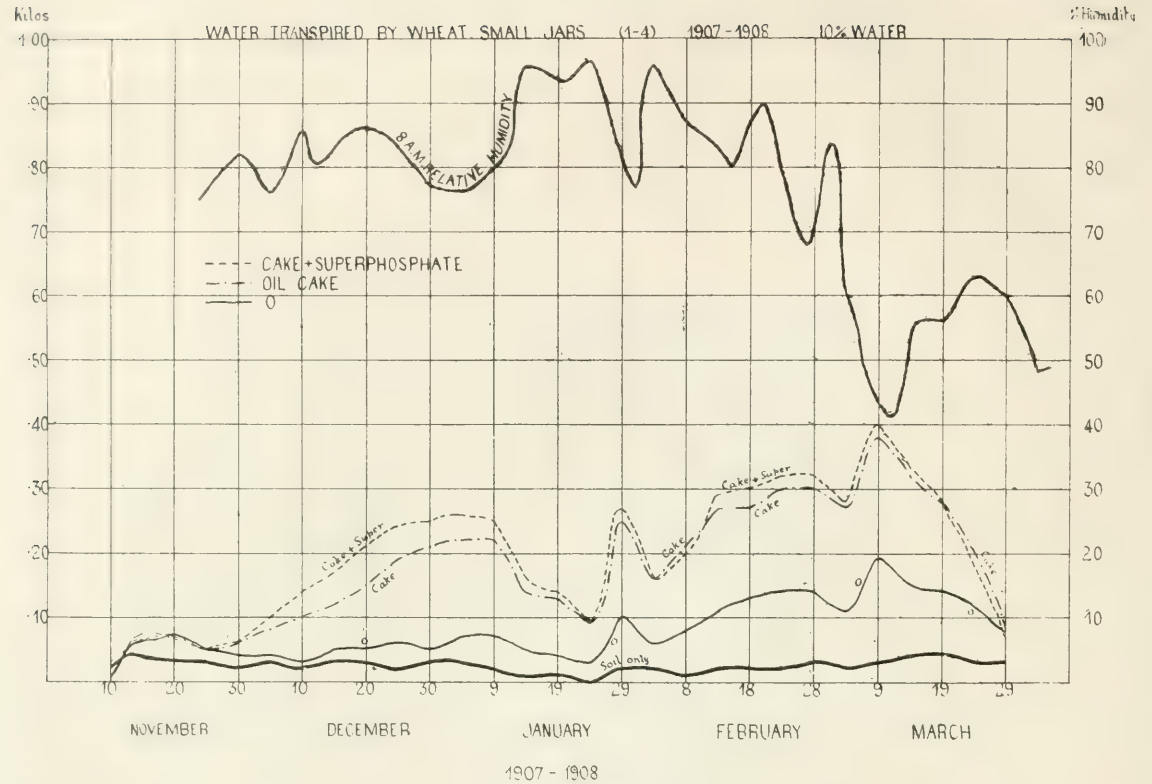
STATEMENT IV.

TRITICUM SAT. (WHEAT) 1907-08.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry Crop. Seed. Grms.	Dry Crop. Total. Grms.	Water transpired. Kilos.	Ratio.
1	A = 9″ diam. × 12″ deep.	About 15 kilos of Pusa soil.	10	Blank Jar.					(3·13)	
2			10	Nil.	31-10-07	30-3-08	3·65	12 31	7·80	634
3			10	Rape cake	31-10-07	30-3 08	13 79	42·20	22·08	523
4			10	Rape cake and superphosphate.	31-10 07	30-3-08	14·66	42·85	24·45	571
5			20	Blank Jar.						
6			20	Nil.	31-10 07	6-4-08	1·79	8·58	9·72	1133
7			20	Rape cake	31 10 07	30-3-08	10 87	34·11	24·72	725
8			20	Rape cake and superphosphate.	31-10 07	30-3-08	12·71	38·49	27·91	725
501	C = 9″ diam. × 22″ deep.	About 29 Kilos of Pusa soil.	10	Blank Jar.					(7·03)	
502			10	Nil.	30 10 07	6-4-08	5·02	16. 5	11·49	696
503			10	Rape cake	30 10-07	30-3-08	15·19	47.84	23 92	500
504			10	Rape cake and superphosphate.	30-10-07	30-3-08	22·37	67·03	29 90	446
505			20	Blank Jar.						
506			20	Nil.	30-10-07	6-4 08	4·83	23·31	19·14	821
507			20	Rape cake.	30 10 07	30-3-08	37·99	132·79	76·42	575
508			20	Rape cake and superphosphate.	30 10-07	30-3 08	33·55	120·44	60·87	505

The *Rape cake* used was equivalent to ·005 grm. N. per 100 grms. soil; the superphosphate was sufficient to increase the phosphate in the manure to ·01 grm. soluble phosphoric acid per 100 grms. soil.

CHART IV*a*.


Kilos
% Humidity
WATER TRANSPIRED BY WHEAT. SMALL JARS (1-4) 1907-1908 10% WATER
8 A.M. RELATIVE HUMIDITY
CAKE+SUPERPHOSPHATE
OIL CAKE
0
Cake+Super.
Cake
Soil only
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
1907 - 1908

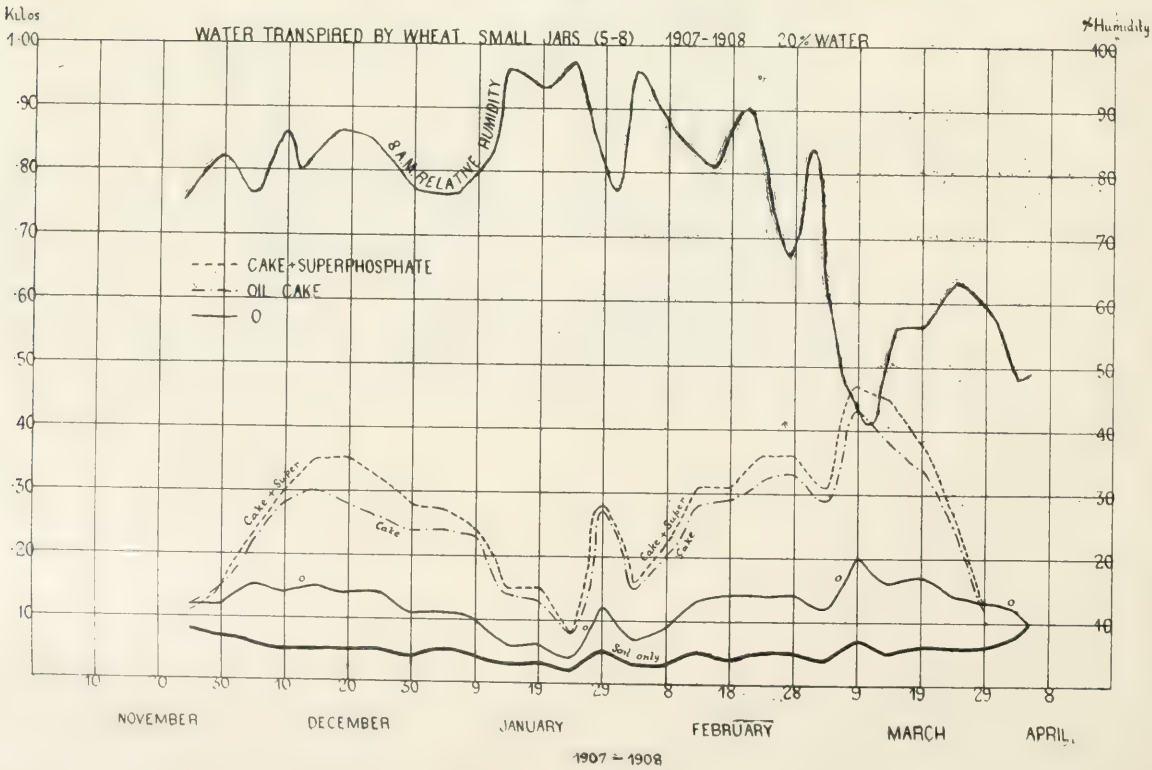
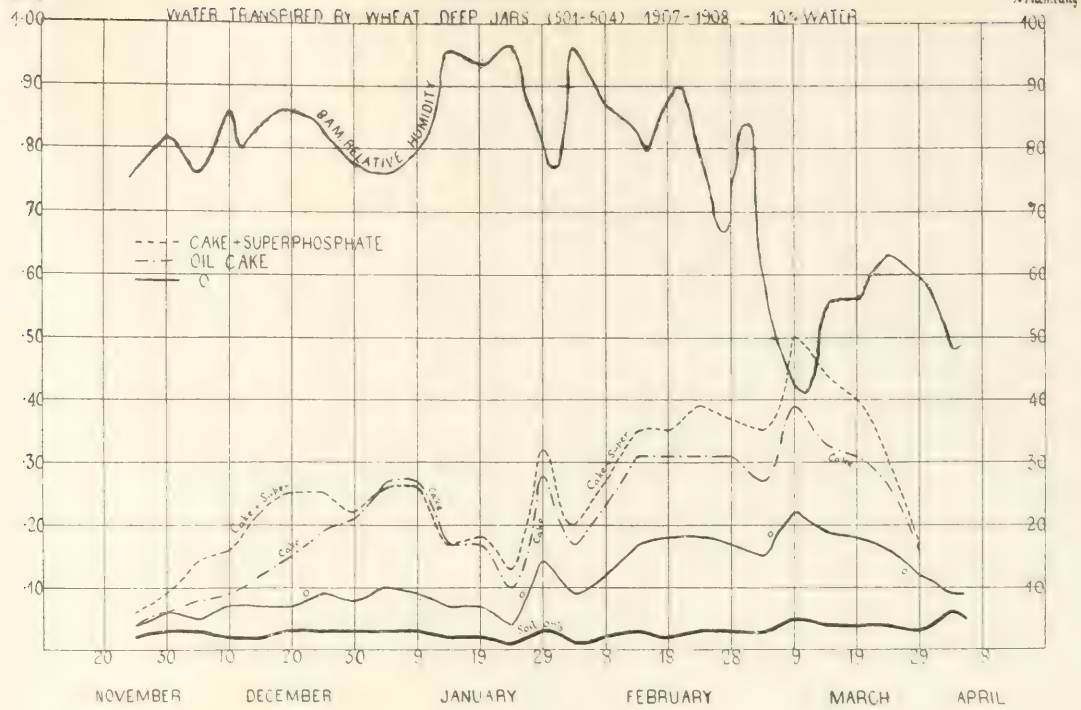
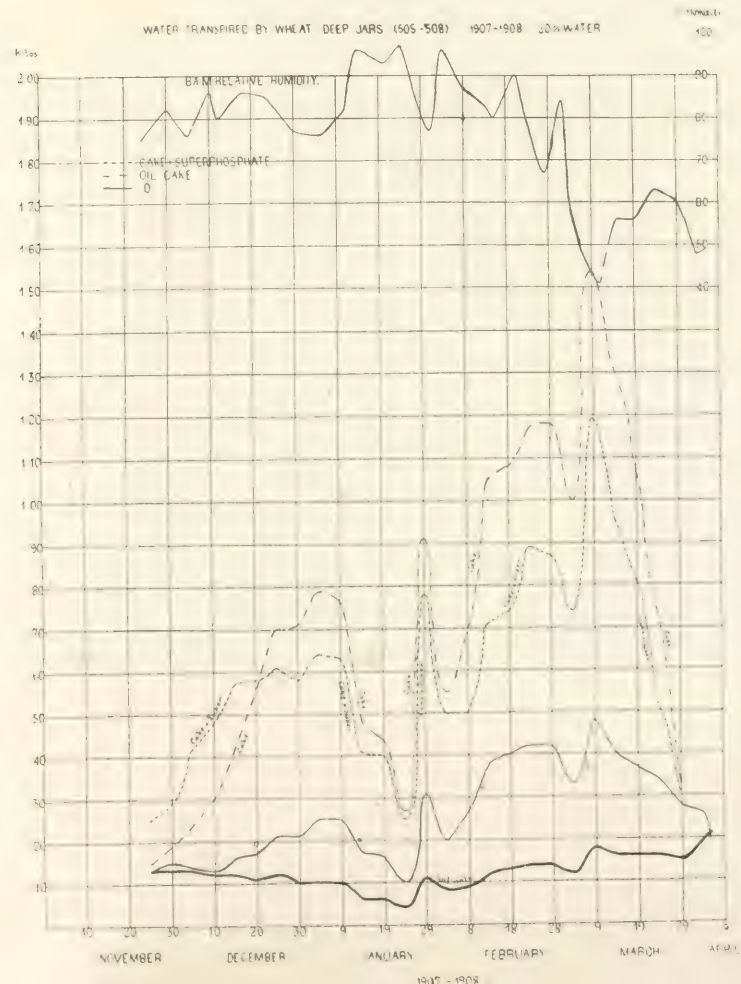

Kilos
% Humidity
WATER TRANSPIRED BY WHEAT. SMALL JARS (5-8) 1907-1908 20% WATER
8 A.M. RELATIVE HUMIDITY
CAKE+SUPERPHOSPHATE
OIL CAKE
0
Cake+Super.
Cake
Soil only
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
1907 - 1908

CHART IVb.


Kilos
% Humidity
WATER TRANSPIRED BY WHEAT DEEP JARS (501-504) 1907-1908 10% WATER
9AM RELATIVE HUMIDITY
CAKE + SUPERPHOSPHATE
OIL CAKE
0
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
1907 - 1908


WATER TRANSPIRED BY WHEAT DEEP JARS (505-508) 1907-1908 10% WATER
Kilos
9AM RELATIVE HUMIDITY
CAKE + SUPERPHOSPHATE
OIL CAKE
0
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
1907 - 1908

STATEMENT V.

Triticum sat. (Wheat) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
115	A = 9″ diam. × 12″ deep.	About 14 kilos. of Pusa soil.	20		Blank	jars			(8·49)	
116			20	Nil	5-11-08	23-3-09	4·09	17·02	14·43	848
117			20		5-11-08	23-3-09	4·56	16·81	14·83	882
118			20	N	5-11-08	23-3-09	3·23	17·80	15·24	856
119			20		5-11-08	23-3-09	4·08	15·77	11·19	709
120			20	N + P	5-11-08	23-3-09	20·06	64·92	34·82	536
			20		5-11-08	23-3-09	18·72	62·05	29·73	479

N = Ca $(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART V.

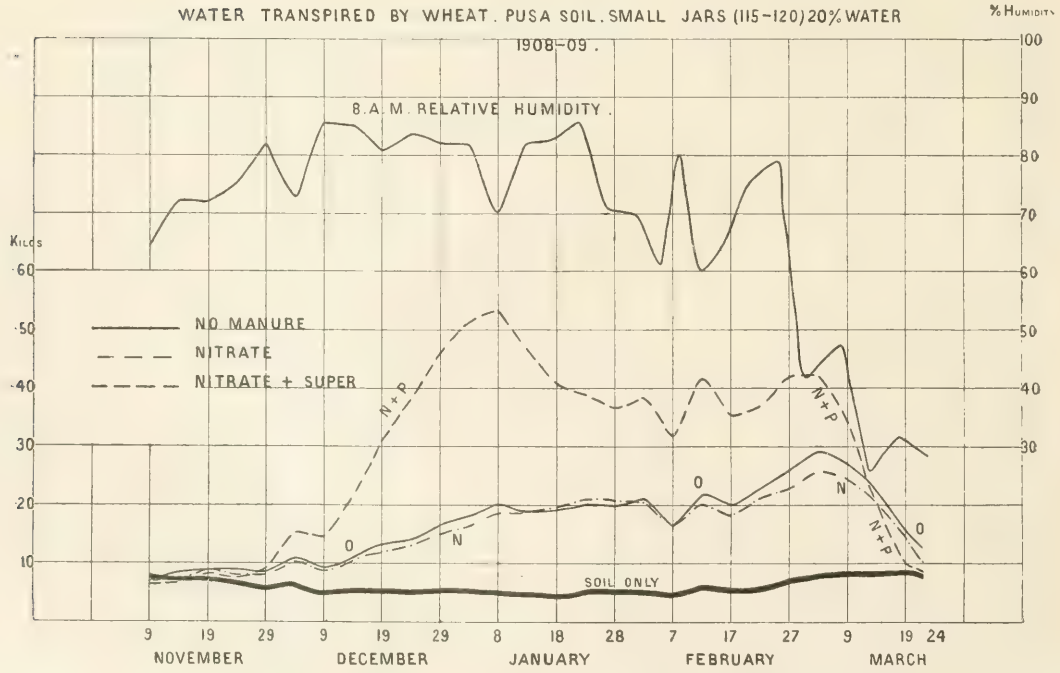
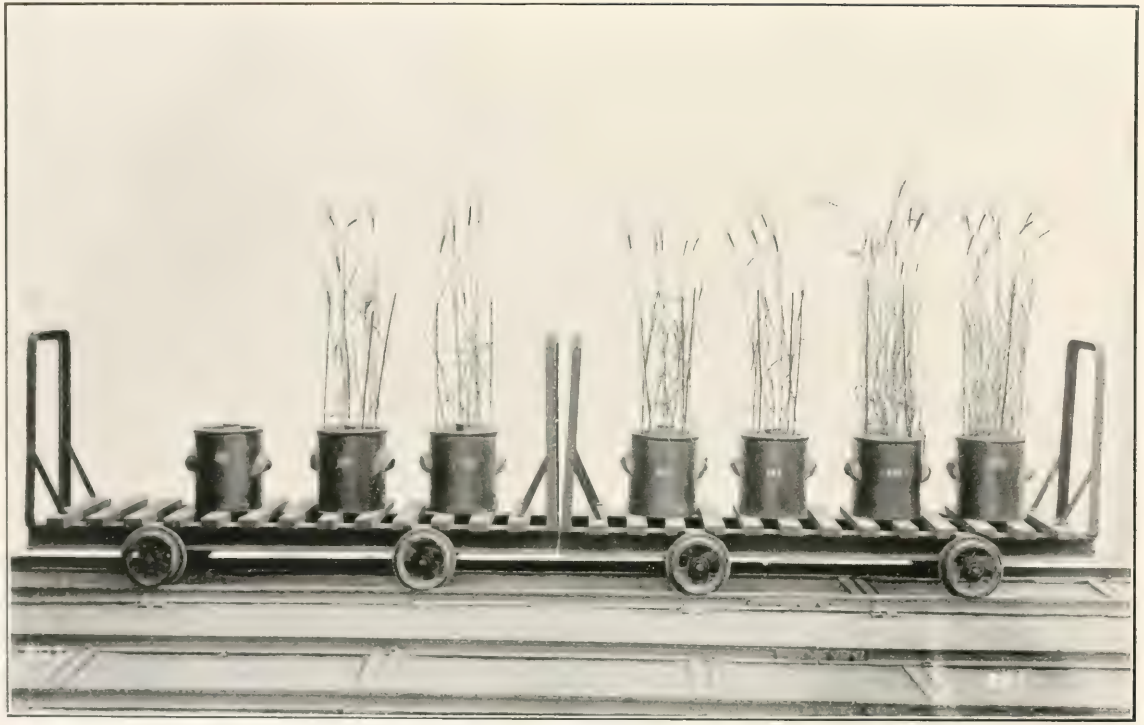


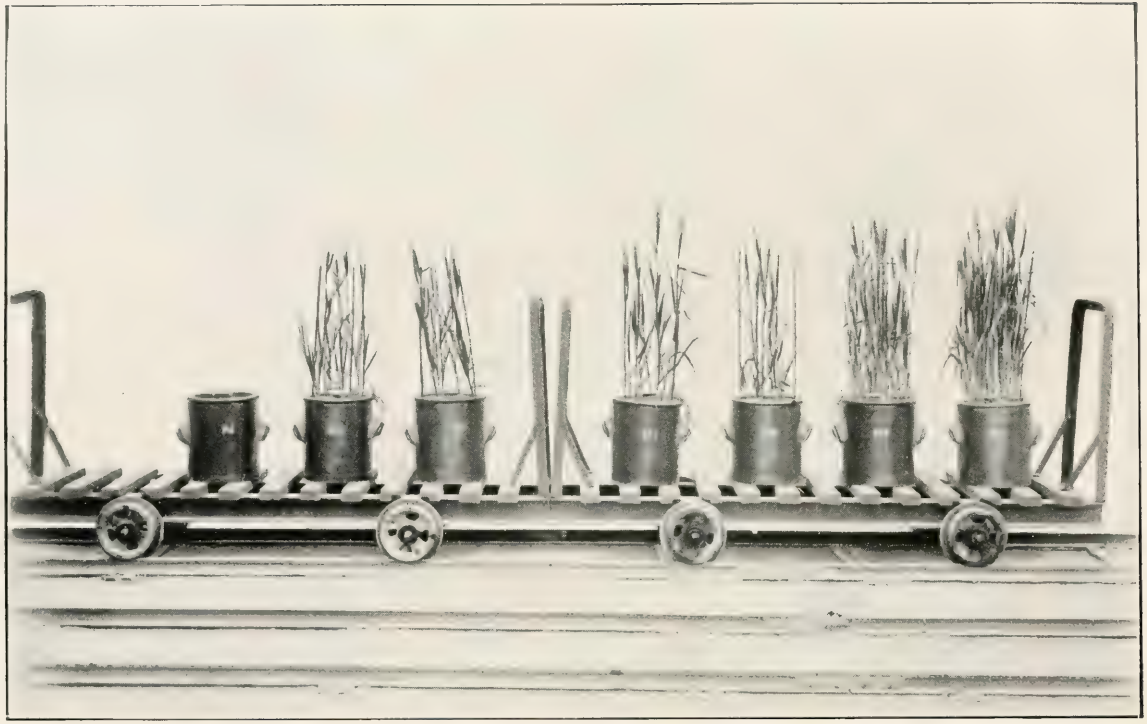
PLATE V.



WHEAT, 1908-9.

115, 116. No manure.
117, 118. Nitrate only.
119, 120. Nitrate and Superphosphate.

PLATE VI.



BARLEY, 1908-9.

109, 110. No manure.
111, 112. Nitrate only.
113, 114. Nitrate and Superphosphate.

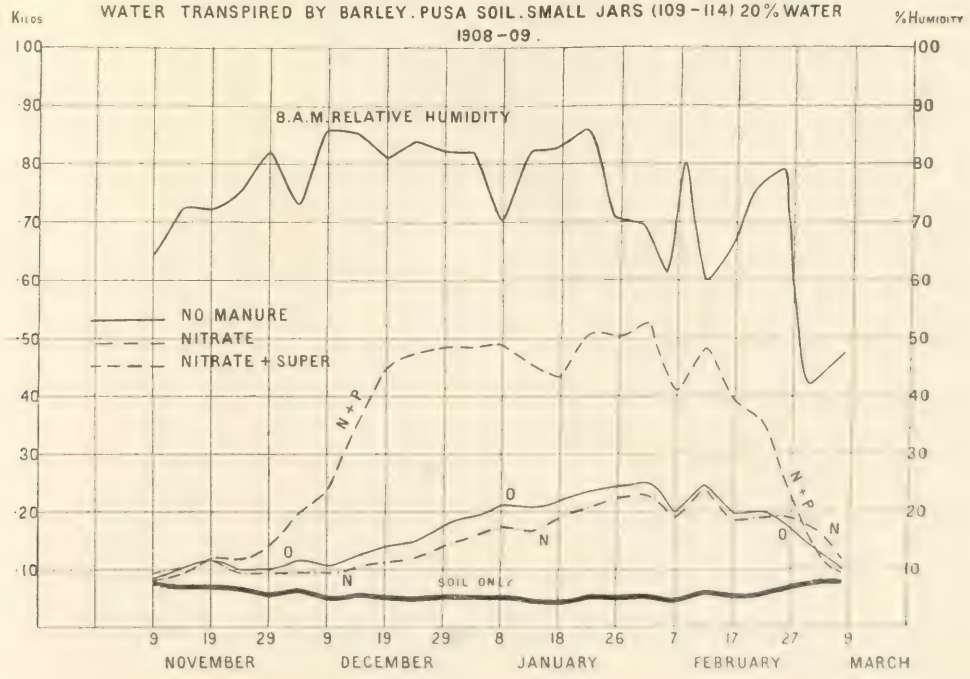
STATEMENT VI.

Hordeum vulg. (Barley) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
...	A - 9" diam. × 12" deep.	About 14 kilos of Pusa soil.	20		Blank jars		...	...	(7·09)	...
109			20	Nil	2-11-08	8-3-09	9·5	19·9	13·52	679
110			20	Nil	2-11-08	8-3-09	9·5	19·2	12·97	676
111			20	N	2-11-08	8-3-09	8·7	28·6	12·08	422
112			20	N	2-11-08	8-3-09	7·5	26·0	11·32	435
113			20	N + P	2-11-08	8-3-09	29·9	61·1	31·58	517
114			20	N + P	2-11-08	8-3-09	34·8	80·8	36·07	446

N = $Ca(NO_3)_2$ = ·005 grm. N; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART VI.



STATEMENT VII.

Avena sat. (Oats) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	×	About 14 kilos of Pusa soil.	20	Blank jars	...	...	...	...	(8·04)	...
83	A = 9″ diam. 12″ deep.		20	Nil	21 10 08	8 3 09	2·65	5·66	6·32	1117
84			20	Nil	21 10 08	8 3 09	5·20	10·98	6·91	629
85			20	N	5 11 08	8 3 09	5·11	11·74	10·23	871
86			20	N	5 11 08	8 3 09	5·30	12·20	9·54	782
87			20	N + P	21 10 08	8 3 09	22·88	52·01	31·83	612
88			20	N + P	21 10 08	8 3 09	30·65	59·58	29·21	490

N = $Ca(NO_3)_2$ = ·015 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART VII.

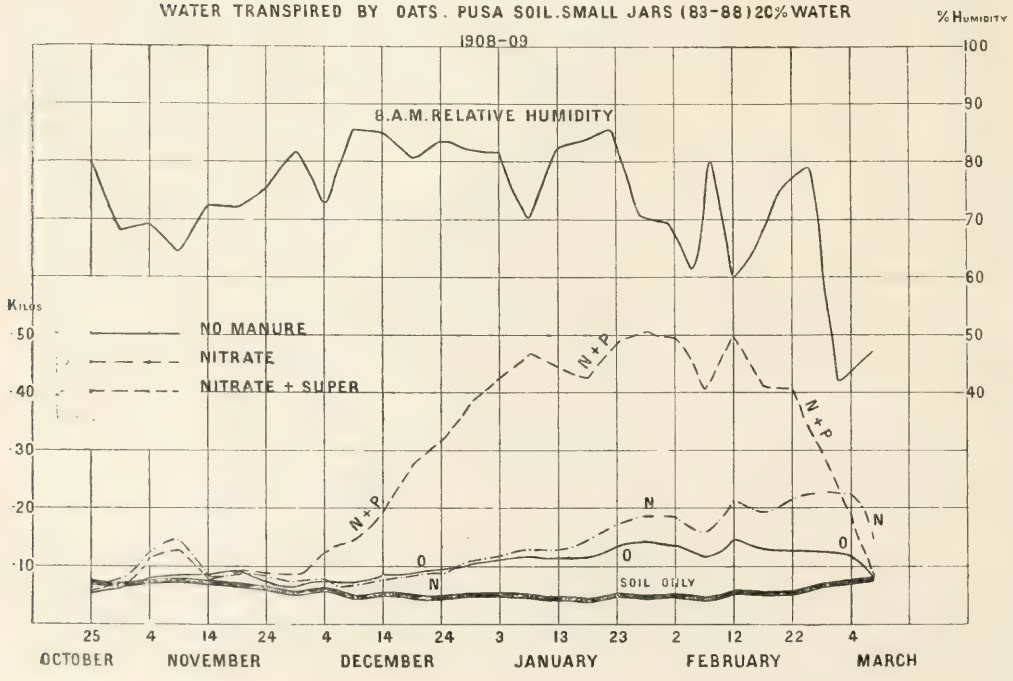
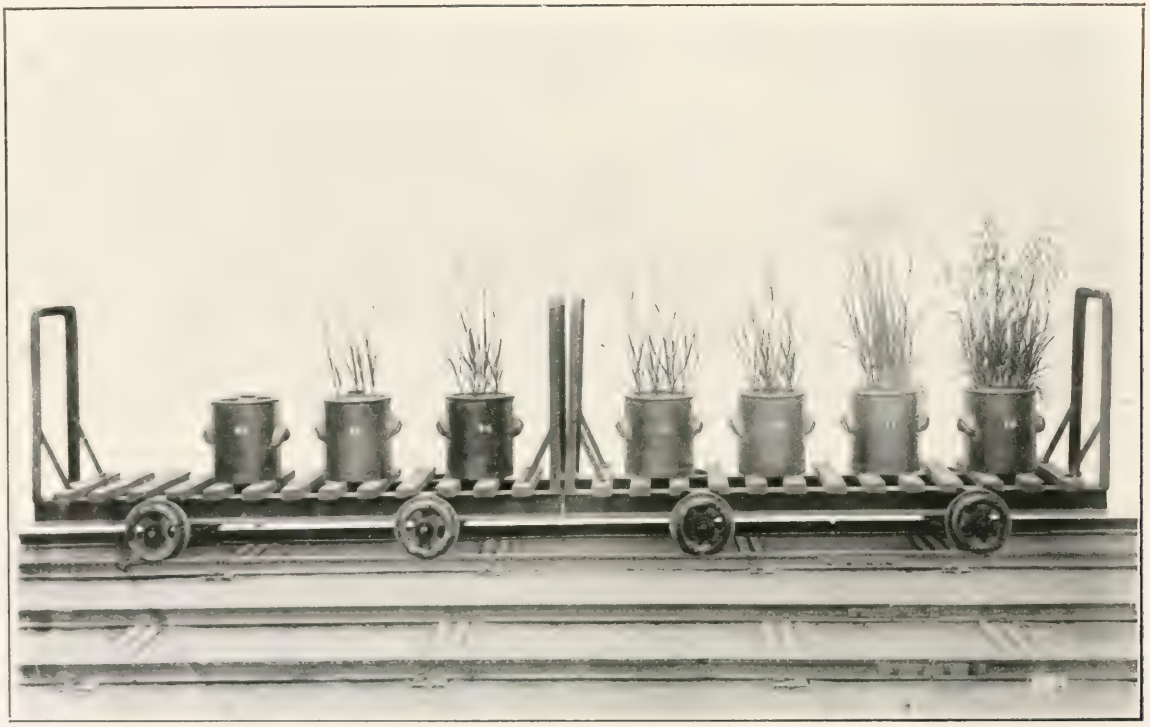


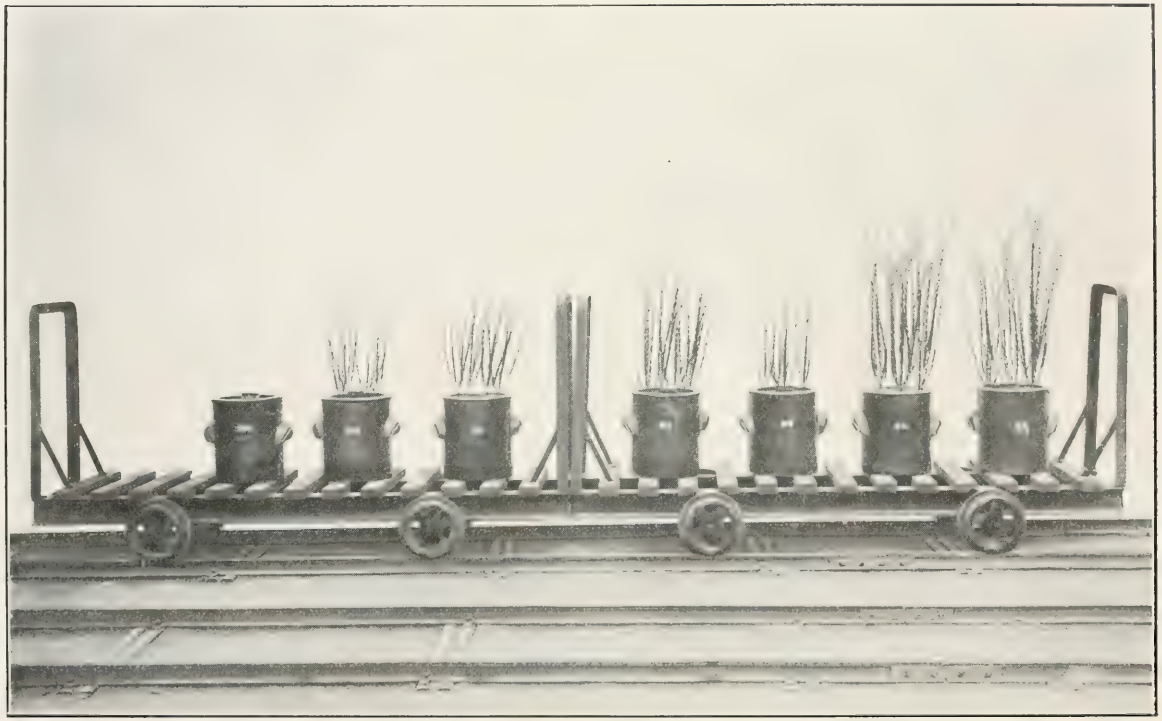
PLATE VII.



OATS, 1908-9.

83, 84. No manure.
85, 86. Nitrate only.
87, 88. Nitrate and Phosphate.

PLATE VIII.



LINSEED, 1908-9.

90, 91. No manure.
92, 93. Nitrate only.
94, 95. Nitrate and Superphosphate.

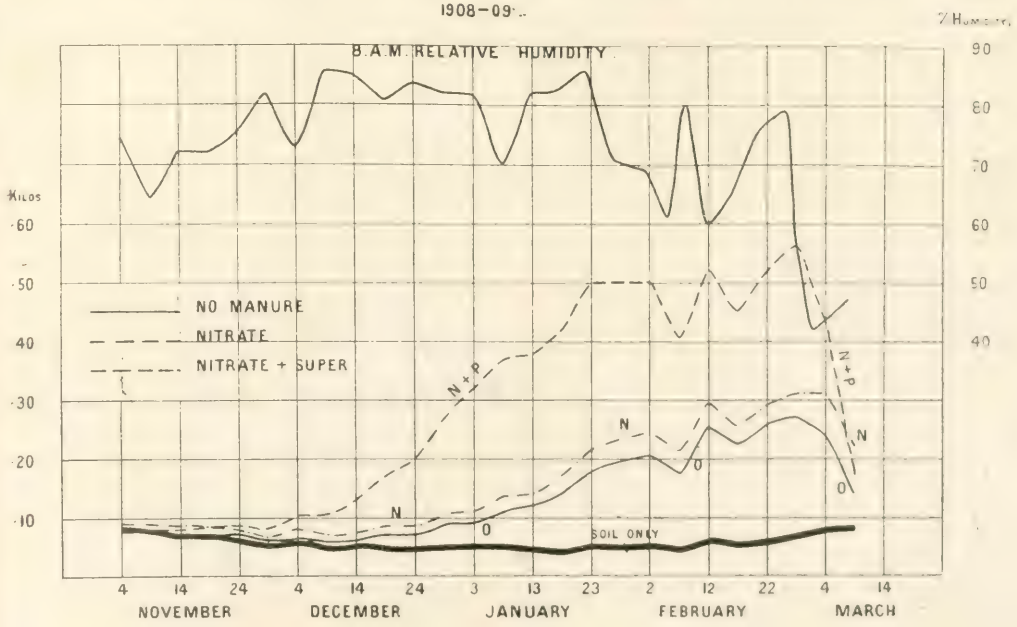
STATEMENT VIII.

GUIZOTIA ABYSS. (LINSEED) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	×	About 14 kilos of Pusa soil.	20	Blank jars					(7·35)	...
90	A=9" diam. 12" deep.		20	Nil	2 11 08	9 3 09	1·91	7·18	8·84	1231
91			20	Nil	2 11 08	9 3 09	2·47	11·17	10·66	954
92			20	N	2 11 08	9 3 09	3·92	15·58	17·13	1099
93			20	N	2 11 08	9 3 09	2·00	7·35	9·53	1297
94			20	N + P	2 11 08	9 3 09	11·68	35·78	34·27	957
95			20	N + P	2 11 08	9 3 09	6·99	24·83	25·90	1043

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART VIII.



STATEMENT IX.

Brassica campestris (Sarson) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	A = 9" diam. 12" deep.	About 14 kilos of Pusa soil.	20	Blank jars			..	...	7·00 / 5·93	...
76			20	Nil	20-10-08	23-1-09	1·65	5·69	4·10	719
77			20	Nil	20-10-08	23-1-09	1·93	6·07	4·60	754
78			20	N	20-10-08	23-1-09	4·36	14·05	12·52	888
79			20	N	20-10-08	23-1-09	6·88	19·81	14·82	748
80			20	N + P	20-10-08	3-2-09	7·06	23·94	15·40	644
81			20	N + P	20-10-08	3-2-09	16·43	55·88	33·82	605

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART IX.

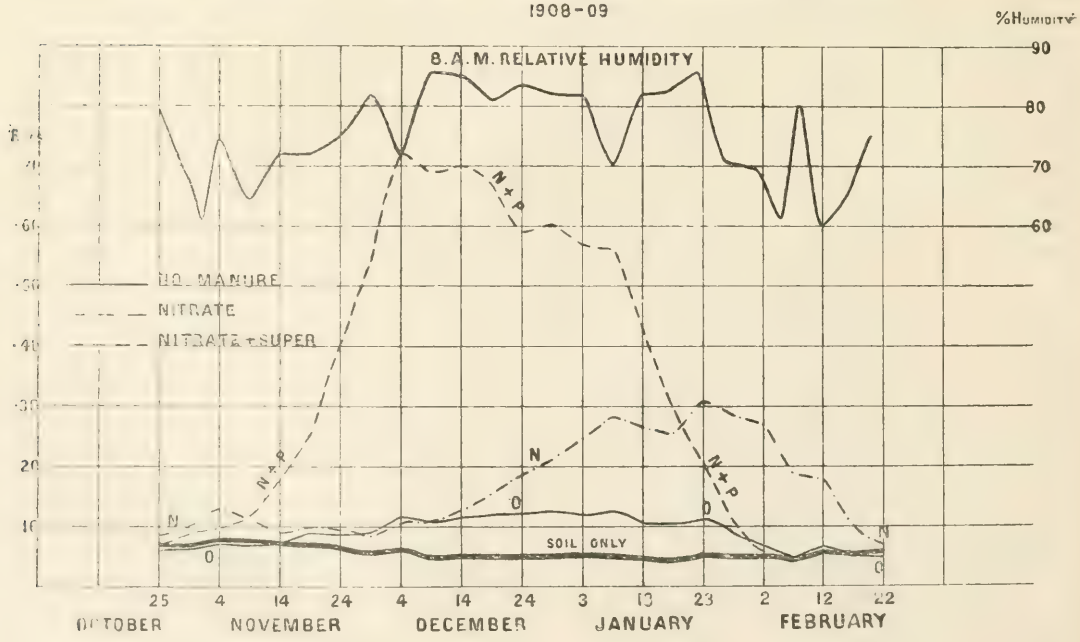
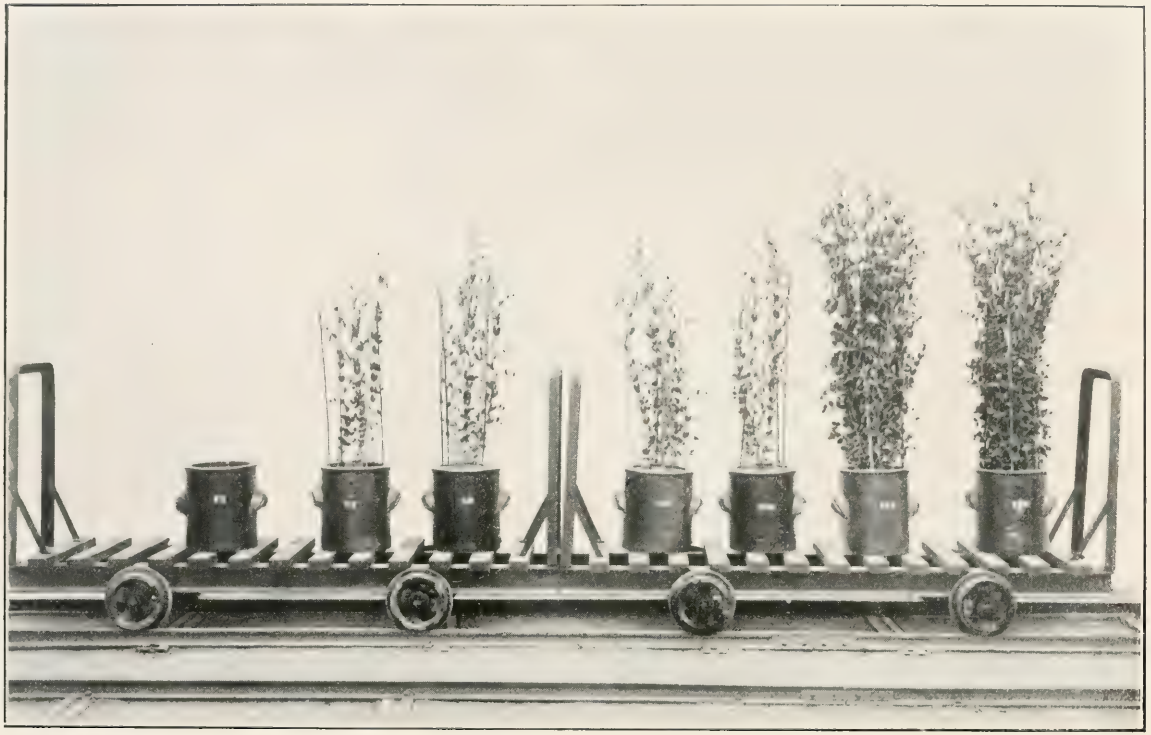


PLATE X.



PEAS, 1908-9.

97, 98. No manure.
99, 100. Nitrate only.
101, 102. Nitrate and Superphosphate.

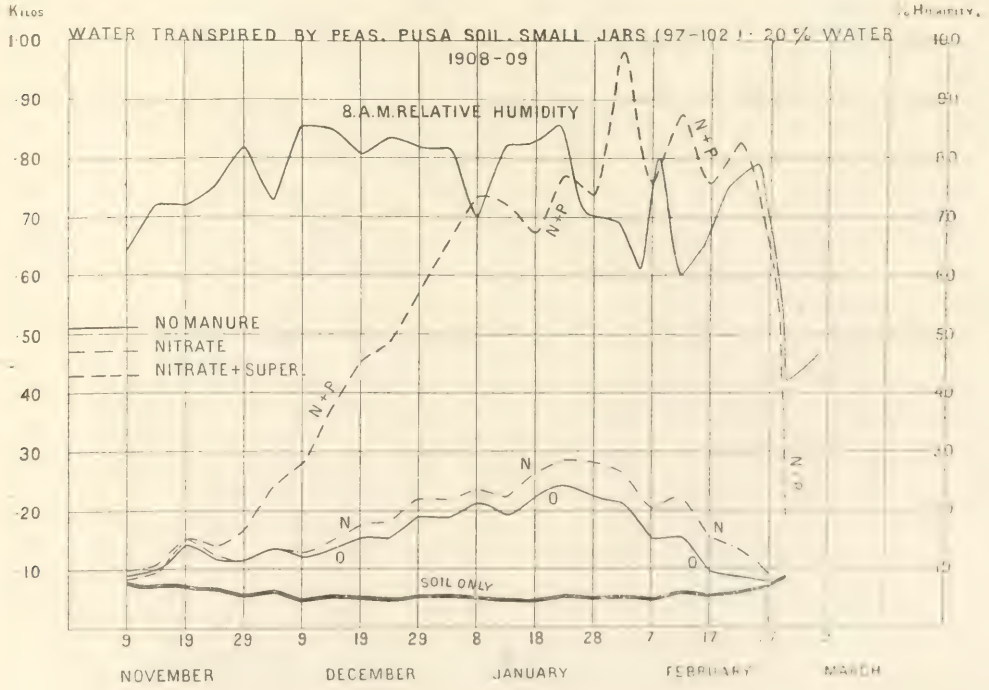
STATEMENT X.

Pisum sat. (Peas) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	A = 9″ diam. × 12″ deep.	About 14 kilos of Pusa soil.	20	Blank jars			...	...	(6·00)	...
97			20	Nil ...	2-11-08	1-3-09	5·5	11·6	11·29	973
98			20	Nil ...	2-11-08	1-3-09	7·2	15·8	11·03	698
99			20	N ...	2-11-08	1-3-09	8·5	20·1	14·94	743
100			20	N ...	2-11-08	1-3-09	6·8	16·6	13·71	826
101			20	N+P ...	2-11-08	3-3-09	47·9	115·7	52·35	453
102			20	N+P ...	2-11-08	3-3-09	36·2	94·9	57·72	608

N = $Ca(NO_3)_2$ = ·005 grm. N; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART X.



STATEMENT XI.

Cicer arietinum (Gram) 1908-09.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	A = 9" diam. × 12" deep.	About 14 kilos of Pusa soil.	20	Blank jars			...	...	(7·09)	...
103			20	Nil ...	2-11-08	8-3-09	2·4	7·0	10·66	1523
104			20	Nil ...	2-11-08	8-3-09	3·7	8·9	11·88	1335
105			20	N ...	2-11-08	8-3-09	4·7	9·9	10·40	1050
106			20	N ...	2-11-08	8-3-09	3·8	10·2	13·49	1323
107			20	N+P ...	2-11-08	8-3-09	7·2	21·1	23·78	1127
108			20	N+P ...	2-11-08	8-3-09	30·7	67·1	55·36	825

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XI.

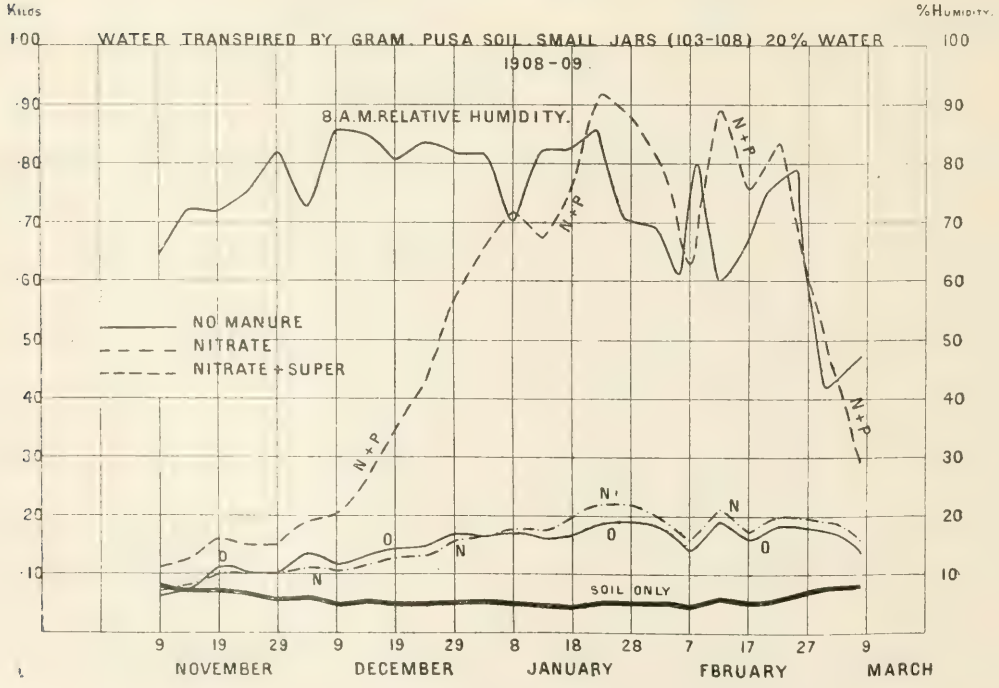
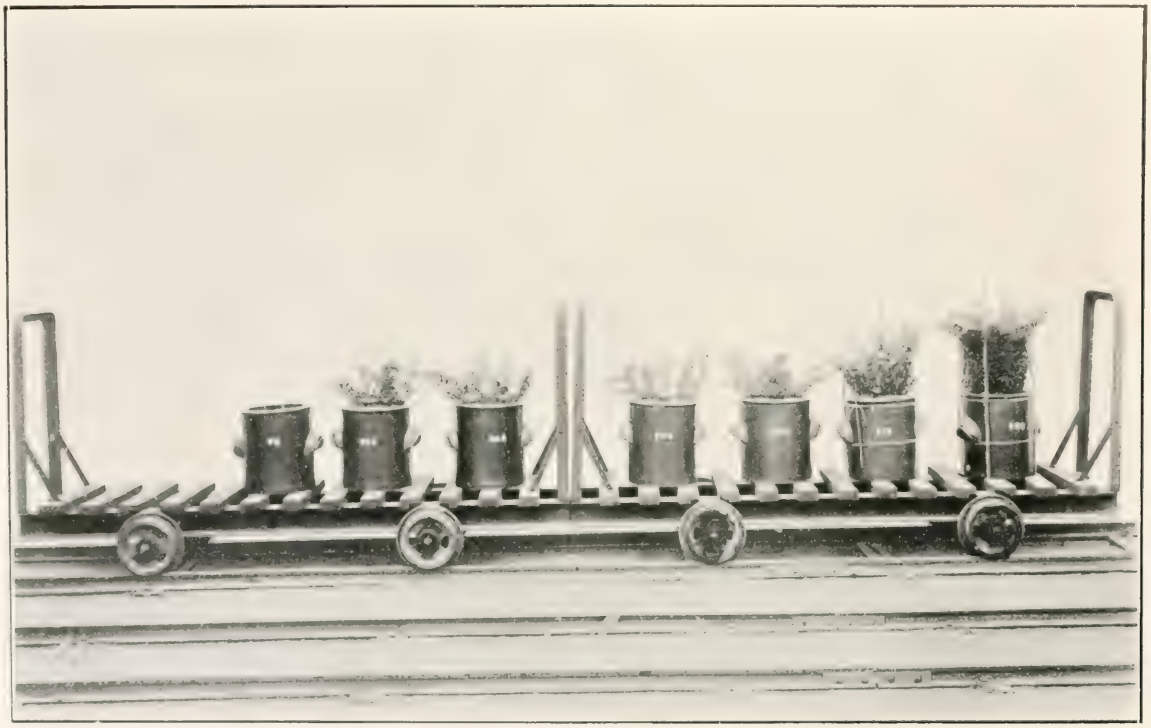


PLATE XI.



GRAM, 1908-9.

103, 104. No manure.
105, 106. Nitrate only.
107, 108. Nitrate and Superphosphate.

STATEMENT XII.

Zea mais (Maize) 1907.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
1	A = 9″ diam. × 12″ deep.	About 15 kilos of Pusa soil.	10	Nil	21-7-07	20-10-07	·05	11·26	5·17	459
2			10	N	21-7-07	20-10-07	Nil	20·07	8·11	404
3			10	N + P	21-7-07	20-10-07	Nil	41·41	11·90	287
4			10	N + P + K	21-7-07	20-10-07	Nil	41·23	14·21	344
5			10	Nil	Blank	jar			(2·27)	
6			15	Nil	21-7-07	20-10-07	·1	11·63	4·28	368
7			15	N	21-7-07	20-10-07	·15	28·53	10·78	377
8			15	N + P	21-7-07	20-10-07	4·9	35·10	11·34	323
9			15	N + P + K	21-7-07	20-10-07	·7	24·12	7·79	322
10			15	N + P + K	Blank	jar			(3·65)	
11			20	Nil	21-7-07	20-10-07	Nil	11·26	6·81	604
12			20	N	21-7-07	20-10-07	Nil	17·1	9·05	529
13			20	N + P	21-7-07	20-10-07	1·8	35·82	13·70	382
14			20	N + P + K	21-7-07	20-10-07	·2	51·03	17·15	336
15			20	Nil	Blank	jar	...	...	(3·73)	...

N = Ca $(NO_3)_2$ = ·005 grm. N per 100 grms. soil P = superphosphate = ·010 grm. soluble P_2O_5 and K = K_2SO_4 = ·005 grm. K_2O per 100 grms. soil.

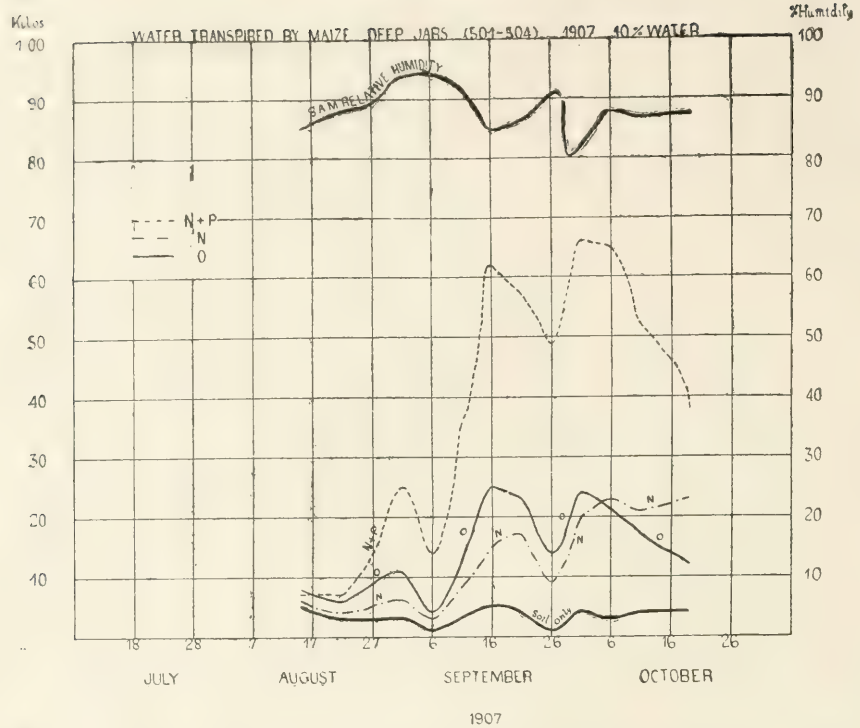
401	B = 9″ diam. × 16″ deep.	About 21 kilos of Pusa soil.	10	Nil	20-7-07	20-10-07	·40	13·0	6·52	500
402			10	N	20-7-07	20-10-07	·40	16·85	10·87	645
403			10	N + P	20-7-07	20-10-07	18·60	67·8	20·96	309
404			10	Nil	Blank	...	...	...	(4·21)	
405			15	Nil	20-7-07	20-10-07	Nil	10·22	6·02	589
406			15	N + P	20-7-07	20-10-07	22·00	92·07	25·86	281
407			15	N + P	Blank	...	...	...	(7·54)	
408			20	Nil	20-7-07	20-10-07	1·30	15·4	5·88	381
409			20	N	20-7-07	20-10-07	1·80	21·0	11·16	527
410			20	N + P	20-7-07	20-10-07	5·70	82·7	24·44	295
411			20	Nil	Blank	...	...	...	(9·70)	...

N = Ca $(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

501	C = 9″ diam. × 22″ deep.	About 31 kilos of Pusa soil.	10	Nil ...	20-7-07	19-10-07	Nil	16·8	7·56	450
502			10	N ...	20-7-07	19-10-07	Nil	15·4	6·35	412
503			10	N + P ...	20-7-07	19-10-07	17·8	92·2	24·16	262
504			10	Nil ...	Blank	jar			(3·02)	
505			15	Nil ...	20-7-07	19-10-07	4·8	26·25	11·06	421
506			15	N ...	20-7-07	19-10-07	2·2	29·07	14·68	505
507			15	N + P ...	20-7-07	19-10-07	18·5	97·80	27·97	286
508			15	N + P ...	Blank	jar			(5·73)	
509			20	Nil ...	20-7-07	19-10-07	1·4	30·75	13·20	429
510			20	N ...	20-7-07	19-10-07	1·8	34·03	18·73	489
511			20	N + P ...	20-7-07	19-10-07	4·7	112·08	33·33	295
512			20	Nil ...	Blank	jar			(9·16)	

N = Ca $(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XII*a*.


WATER TRANSPIRED BY MAIZE DEEP JARS (501-504) 1907 10% WATER
Kilos
% Humidity
9 A.M. RELATIVE HUMIDITY
N+P
N
0
Soil only
JULY
AUGUST
SEPTEMBER
OCTOBER
1907

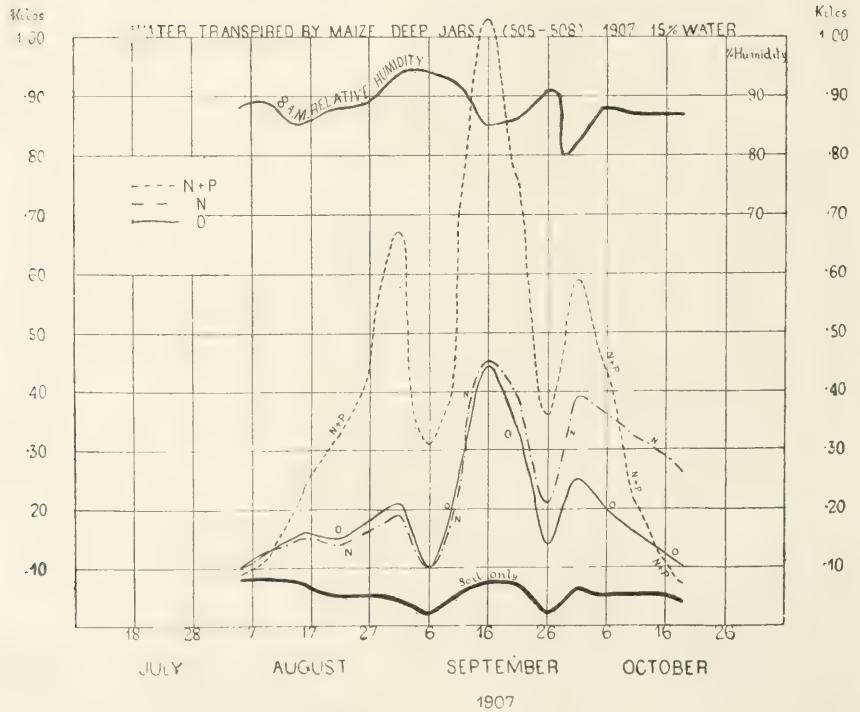
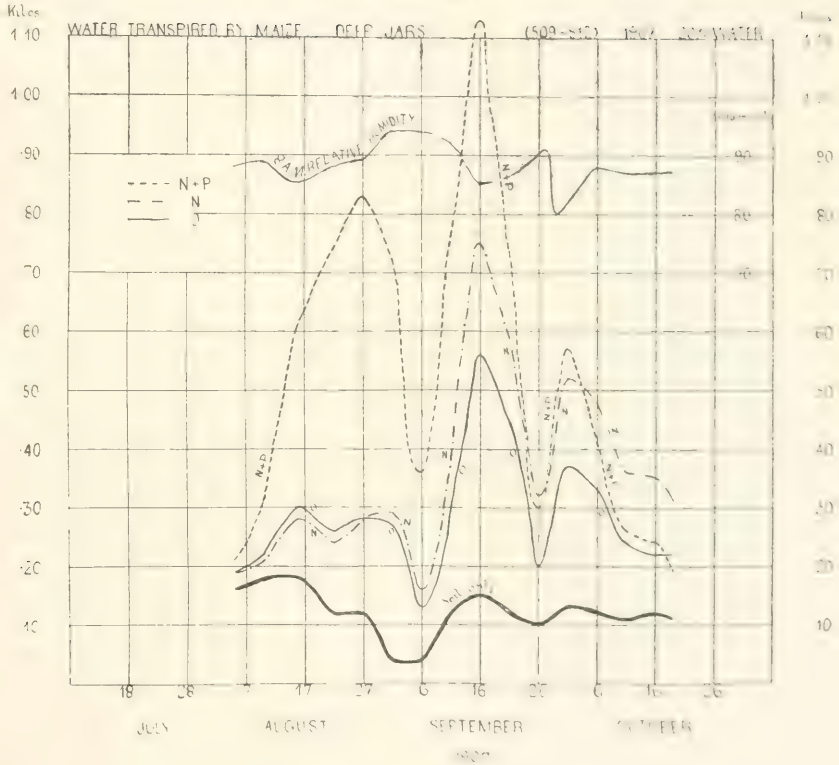

WATER TRANSPIRED BY MAIZE DEEP JARS (505-508) 1907 15% WATER
Kilos
% Humidity
9 A.M. RELATIVE HUMIDITY
N+P
N
0
Soil only
JULY
AUGUST
SEPTEMBER
OCTOBER
1907

CHART XIII.


Kilos
1·10
1·00
·90
·80
·70
·60
·50
·40
·30
·20
·10
WATER TRANSPIRED BY MAIZE. POTS JARS
N+P
N
JULY
AUGUST
SEPTEMBER

STATEMENT XIII.

Zea mais (Maize) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
1 & 2	A = 9" diam. × 12" deep.	About 14 kilos of Pusa soil.	20	.....	Blank jars		...	...	(7·80)	...
3			20	Nil ...	8-6-08	17-9-08	Nil ...	31·4	14·02	446
4			20	Nil ...	8-6-08	17-9-08	Nil ...	31·5	12·51	397
5			20	N ...	8-6-08	17-9-08	Nil ...	30·4	14·58	480
6			20	N ...	8-6-08	17-9-08	·2	32·8	13·01	397
7			20	N+P ...	8-6-08	17-9-08	Nil ...	49·9	22·41	444
			20	N+P ...	8-7-08	17-9-08	·5	65·0	27·41	422

N = $Ca(NO_3)_2$ = ·005 grm. N; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XIII.

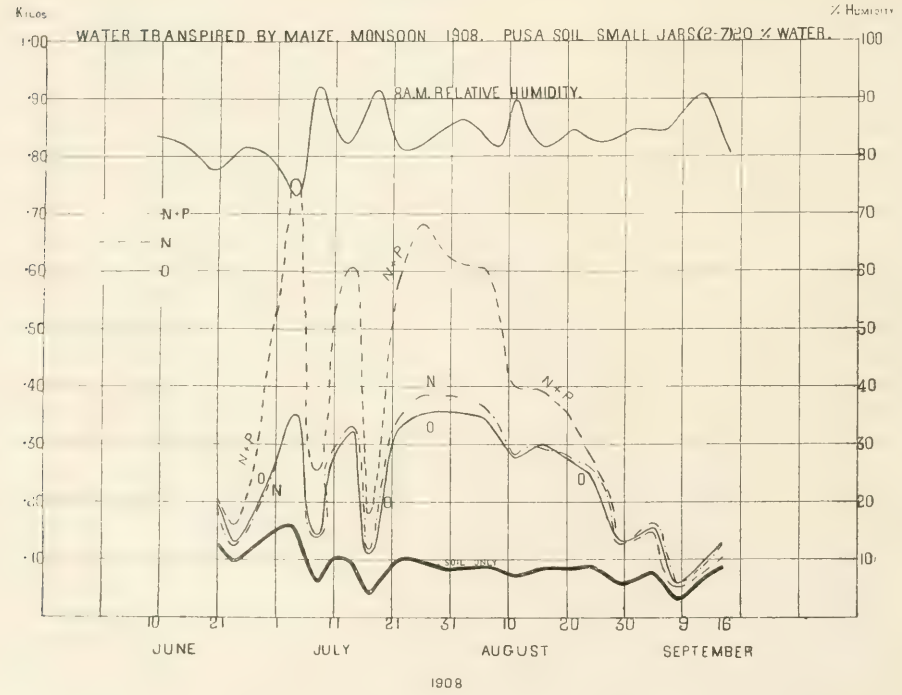
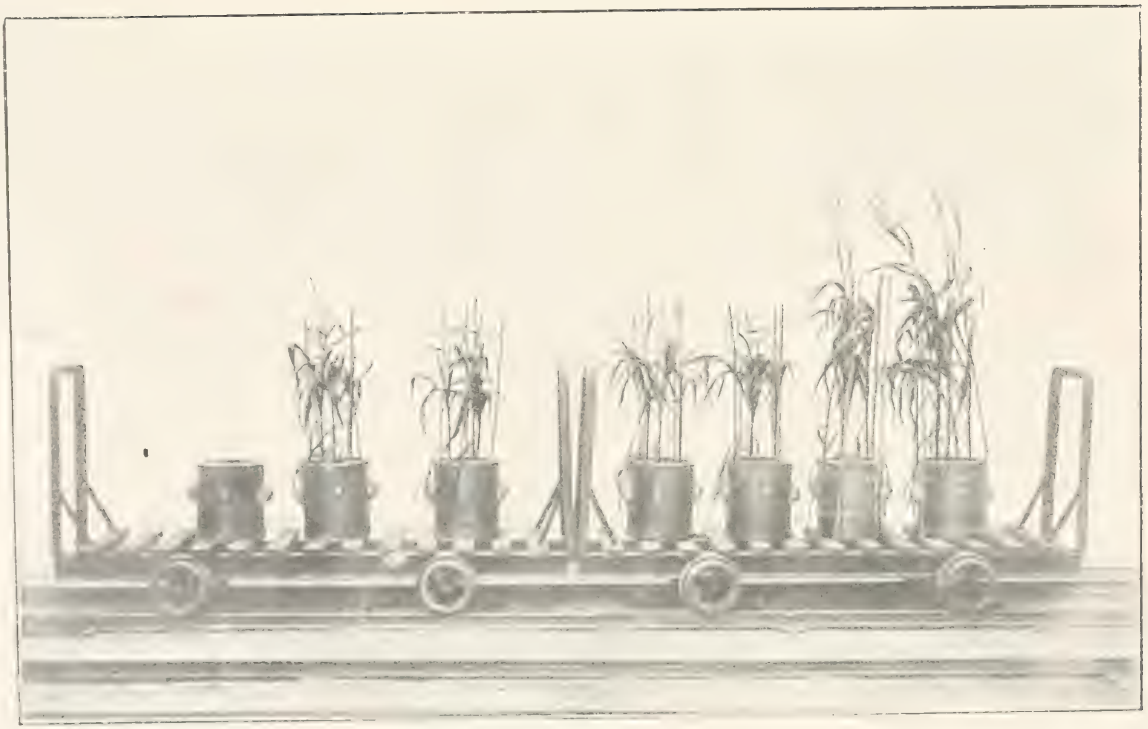


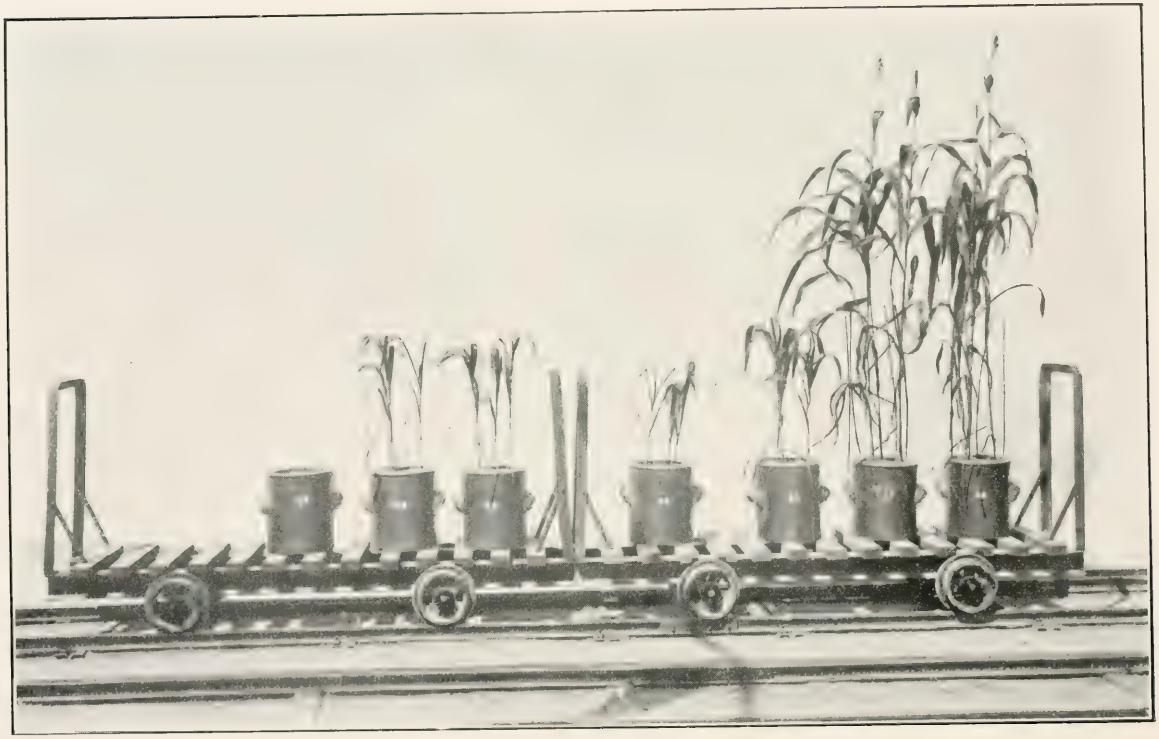
PLATE XIII.



MAIZE, 1908.

2, 3. No manure.
4, 5. Nitrate only.
6, 7. Nitrate and Superphosphate.

PLATE XIV.



JUAR, 1908.

43, 44. No manure.
45, 46. Nitrate only.
47, 48. Nitrate and Superphosphate.

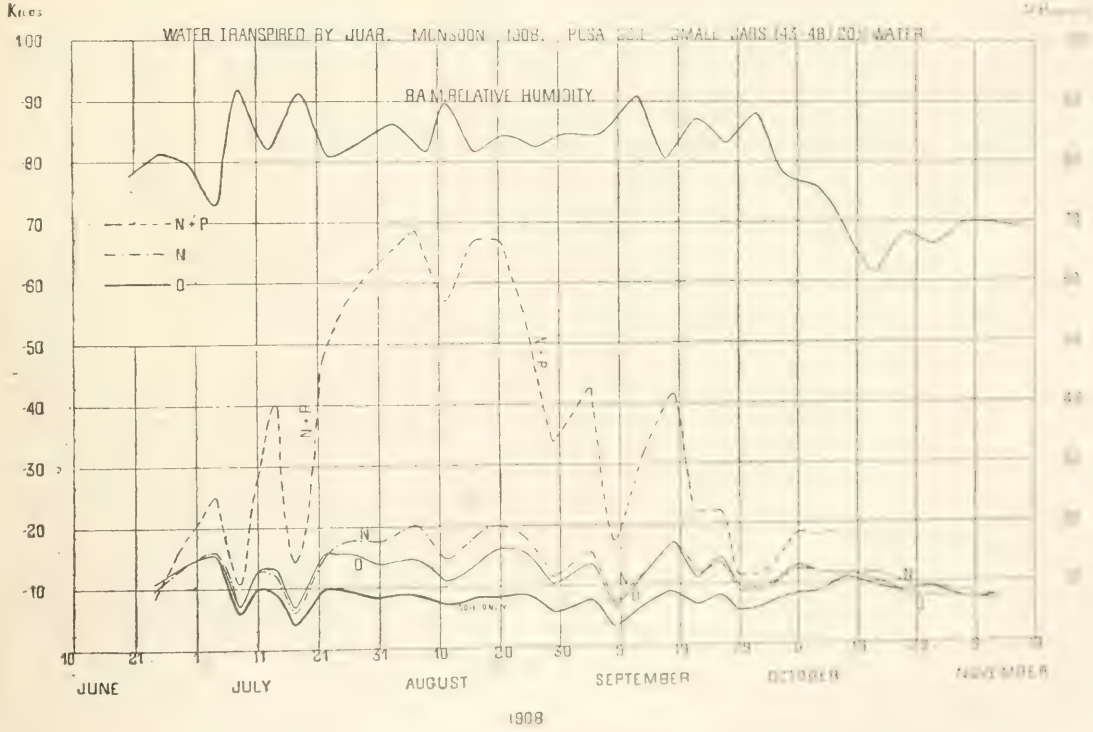
STATEMENT XIV.

Andropogon sorghum (Juar) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	A=9″ diam. × 12″ deep.	About 14 kilos of Pusa soil.	20	...	Blank jars				(11·94)	...
43			20	Nil ...	15-6-08	13-11-08	2·1	12·6	3·40	270
44			20		15-6-08	13-11-08	2·4	14·8	6·67	451
45			20	N ...	15-6-08	13-11-08	1·4	12·7	6·21	489
46			20		15-6-08	13-11-08	1·8	20·3	7·11	350
47			20	N+P ...	15-6-08	16-10-08	5·4	74·3	36·09	486
48			20		15-6-08	16-10-08	9·1	72·5	28·10	388

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XIV.



STATEMENT XV.

Oryza sativa (Rice) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	A = 9″ diam. × 12″ deep.	About 14 kilos of Pusa soil.	20	... ..	Blank jars		...	...	(15·00)	...
23			20	Nil ...	10-6-08	18-12-08	5·4	17·8	20·15	1132
24			20	Nil ...	10-6-08	18-12-08	4·8	22·5	18·45	820
25			20	N ...	10 6-08	18-12-08	6·9	23·7	25·24	1065
26			20	N ...	10-6-08	18-12-08	3·6	24·7	20·62	835
27			20	N+P ...	10-6-08	18-12-08	13·5	43·1	35·48	823
28			20	N+P ...	10-6-08	18-12-08	16·6	62·2	49·64	798

N = $Ca(NO_3)_2$ = ·005 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XV.

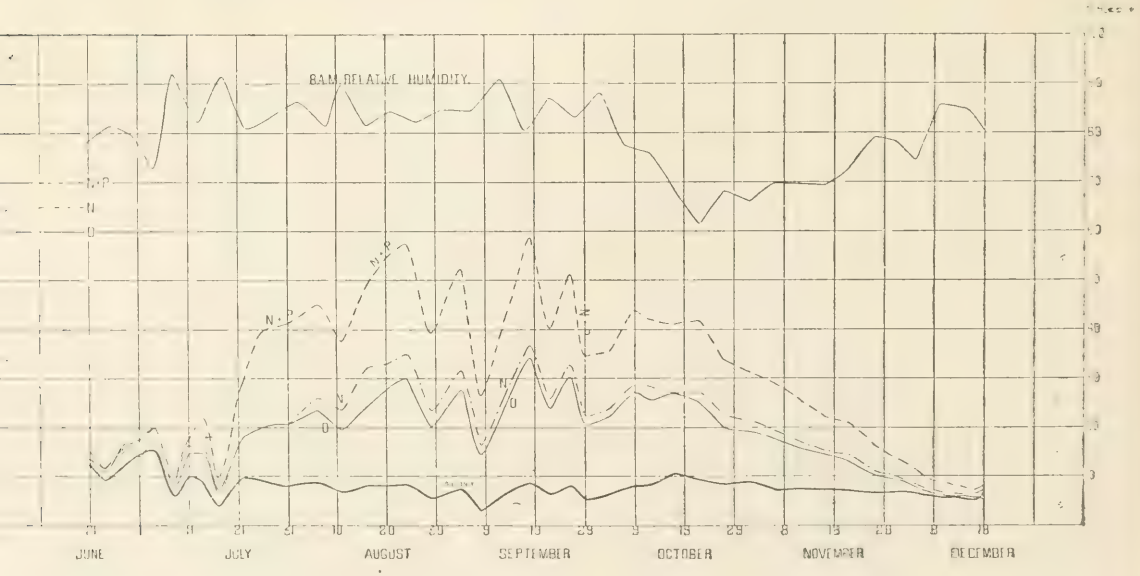
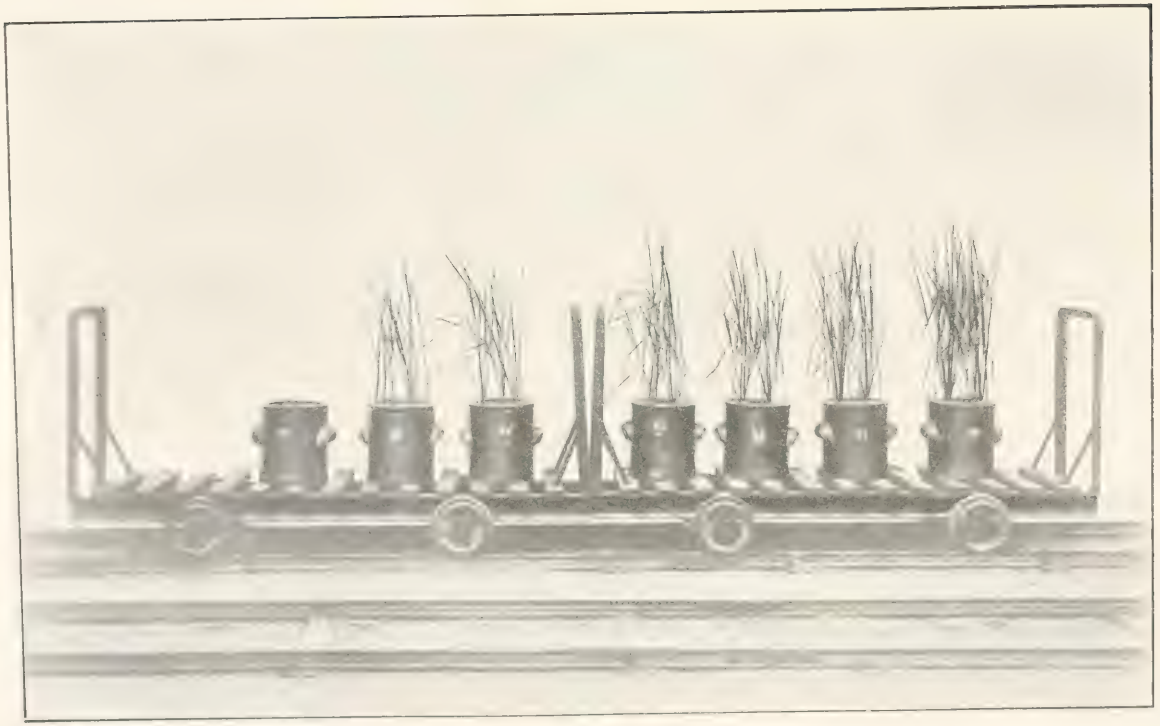


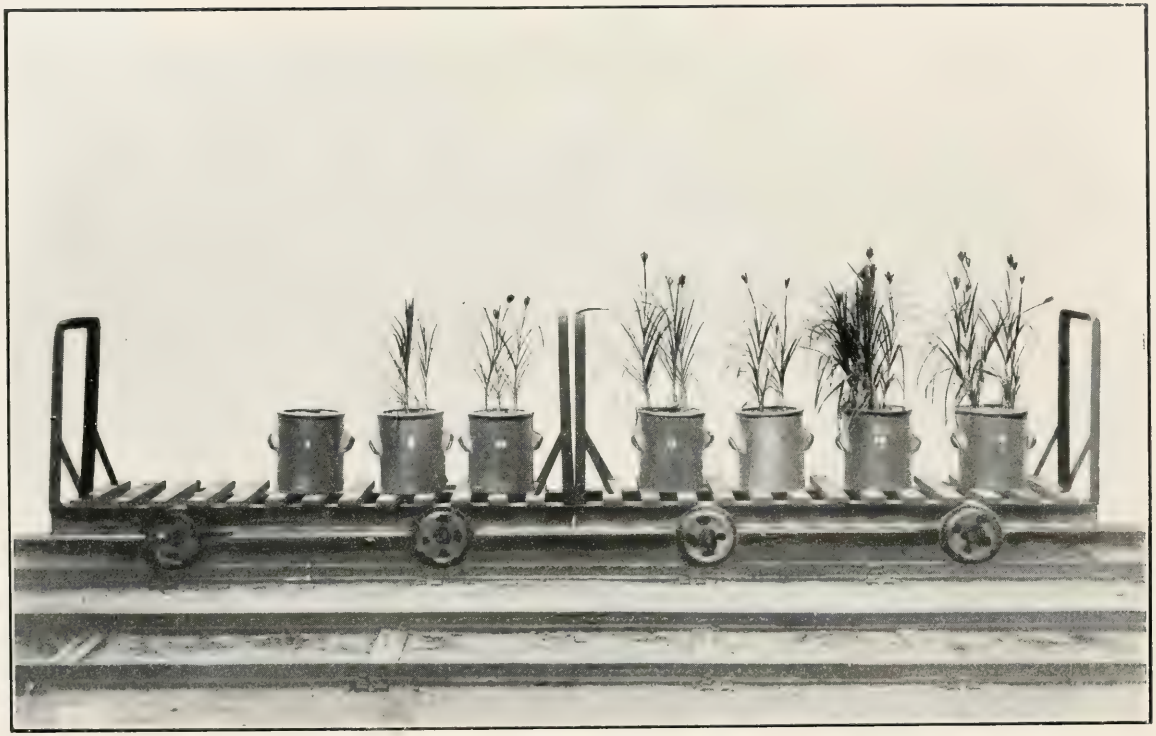
PLATE XV.



RICE, 1908.

23, 24. No manure.
25, 26. Nitrate only.
27, 28. Nitrate and Superphosphate.

PLATE XVI.



MURWA, 1908.

9, 10. No manure.
11, 12. Nitrate only.
13, 14. Nitrate and Superphosphate.

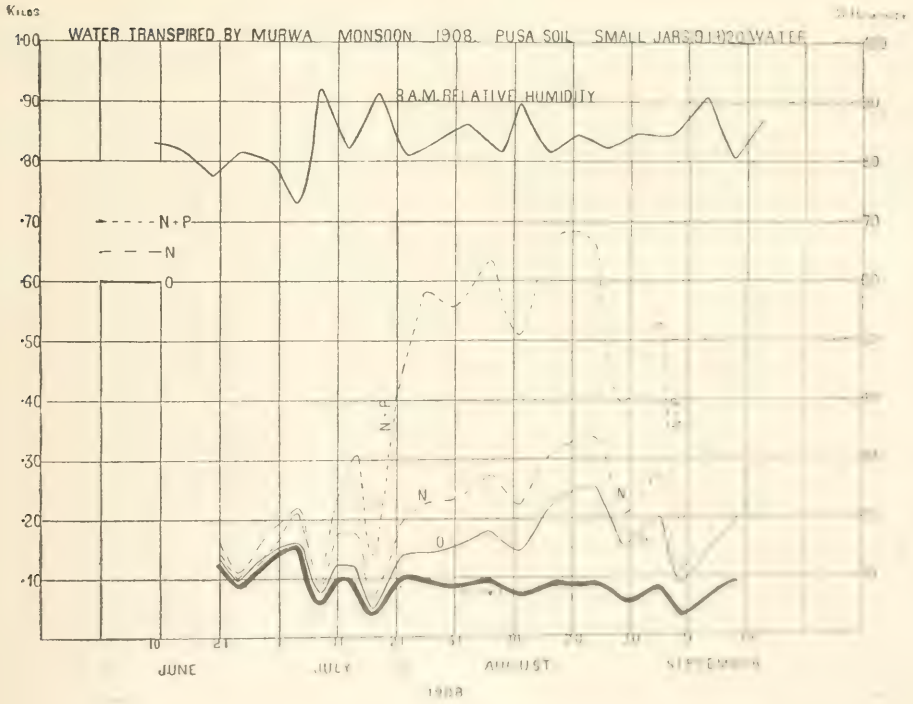
STATEMENT XVI.

ELEUSINE CORACANA (MURWA, RAGI) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	A = 9″ diam. × 12″ deep.	About 14 kilos of Pusa soil.	20	.. ..	Blank jars				7·89	
9			20	Nil ..	9·6·08	19·9·08	4·2	25·0	5·11	204
10			20		9·6·08	19·9·08	4·2	26·6	8·08	304
11			20	N ..	9·6·08	19·9·08	7·2	49·4	15·33	310
12			20		9·6·08	19·9·08	4·5	33·2	8·70	262
13			20	N + P ..	9·6·08	19·9·08	22·6	133·3	35·37	265
14			20		9·6·08	19·9·08	22·1	89·1	23·26	261

N = Ca $(NO_3)_2$ = 0·5 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XVI.



STATEMENT XVII.

PASPALUM SCROBICULATUM (KODO) 1908.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	A = 9″ diam. × 12″ deep.	About 14 kilos of Pusa soil.	20	... ...	Blank jars		...	...	(9·74)	...
16			20	Nil ...	10-6-08	13-10-08	8·9	19·5	6·37	326
17			20	Nil ...	10-6-08	13-10-08	7·9	17·0	8·58	326
18			20	N ...	10-6-08	13-10-08	8·3	22·0	5·71	259
19			20	N ...	10-6-08	13-10-08	10·3	23·8	6·50	273
20			20	N+P ...	10-6-08	13-10-08	35·5	74·2	23·47	316
21			20	N+P ...	10-6-08	13-10-08	19·2	43·7	13·44	307

N = Ca. $(NO_3)_2$ = ·05 grm. N ; P = superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XVII.

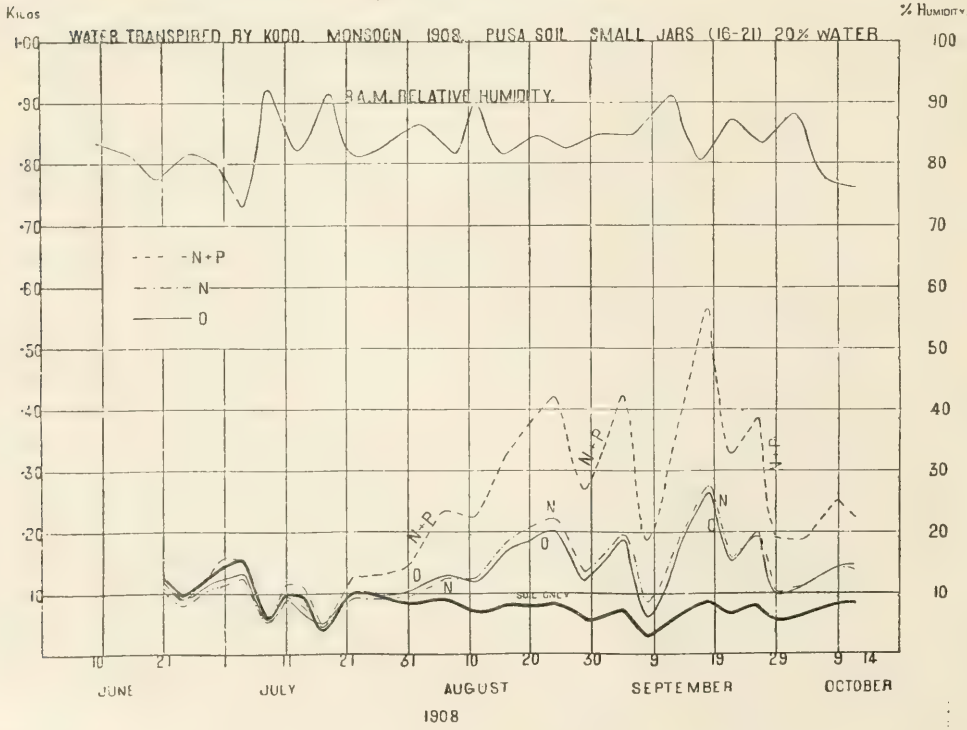
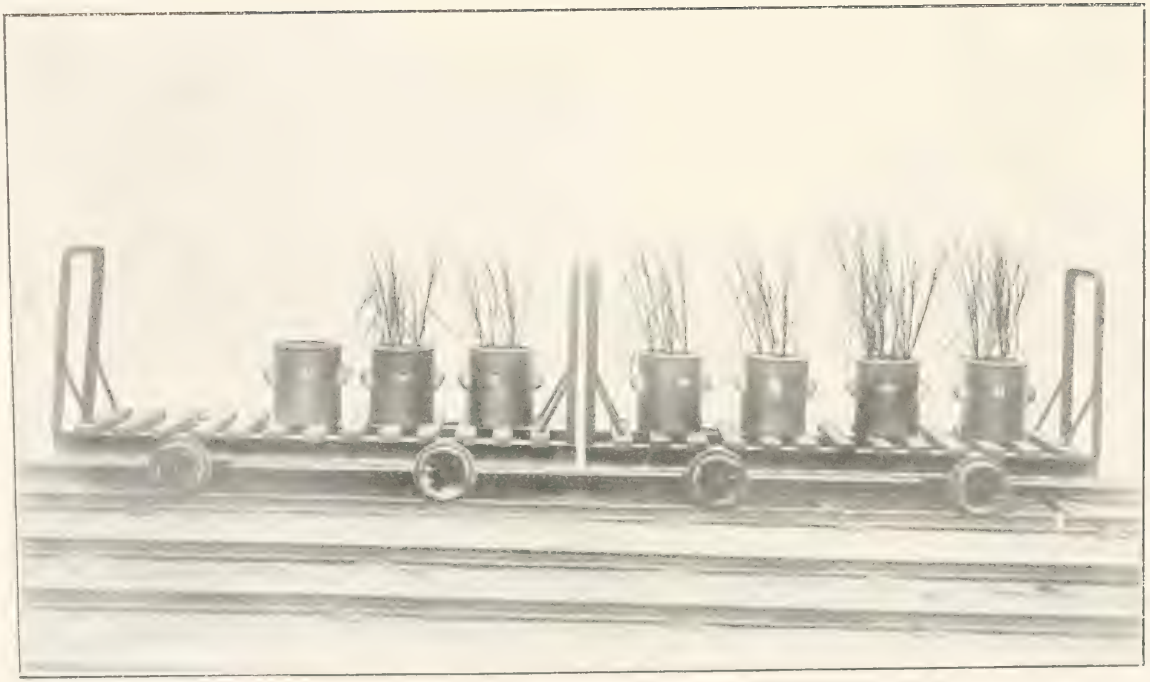


PLATE XVII.



Koiso, 1908.

16, 17. No manure.
18, 19. Nitrate only.
20, 21. Nitrate and Superphosphate.

PLATE XVIII.

ARHAR, 1908-9.

29, 30. No manure.
31, 32. Nitrate only.
33, 34. Nitrate and Superphosphate.
35, 36. Nitrate, Phosphate and Potash.

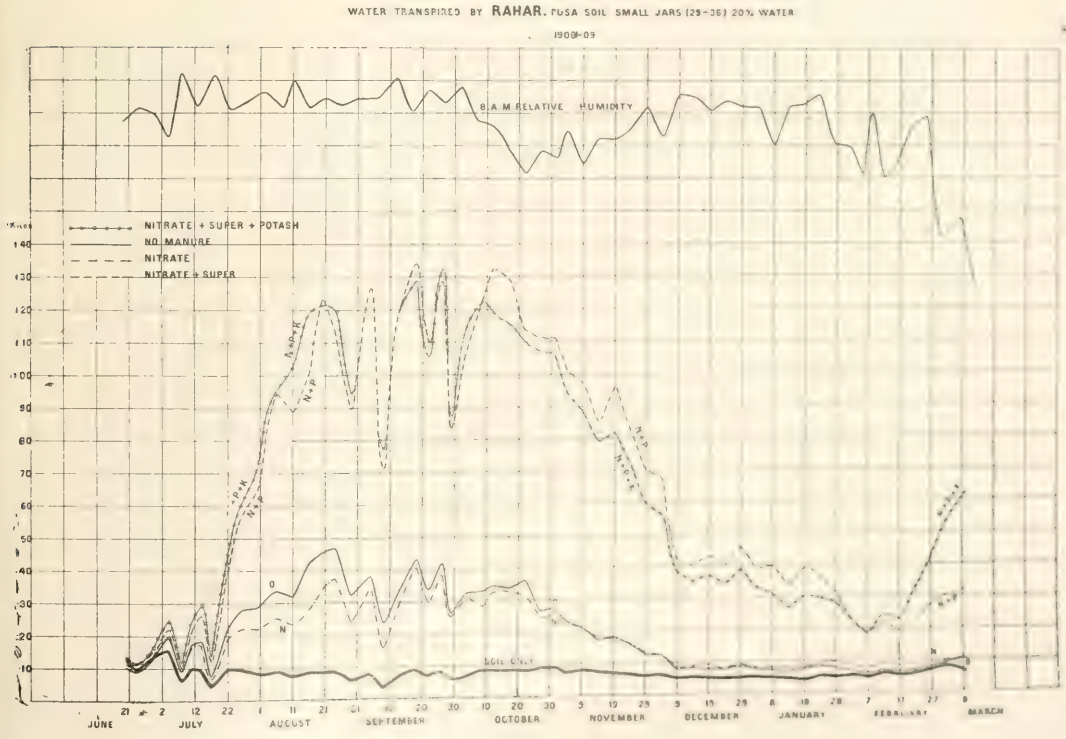
STATEMENT XVIII.

Cajanus Indicus (Rahar) 1908-1909.

Jar No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
			20		Blank jars				(19·00)	
29	About 14 kilos of Pusa soil. A″–9″ diam. 12″ deep.		20	Nil ...	11-6-08	10-3-09	2·4	22·2	26·79	1207
30			20		11-6-08	10-3-09	3·5	40·3	40·74	1011
31			20	N ...	11-6-08	10-3-09	2·4	22·2	24·93	1123
32			20		11-6-08	10-3-09	2·1	24·8	33·90	1367
33			20	N + P ...	11-6-08	10-3-09	33·9	250·4	169·30	676
34			20		11-6-08	10-3-09	35·8	236·2	142·52	603
35			20	N+P+K	11-6-08	10-3-09	28·5	230·2	150·80	655
36			20		11-6-08	10-3-09	29·4	265·2	160·47	605

N = Ca $(NO_3)_2$ = ·005 grm. N ; **P** = superphosphate = ·01 grm. soluble P_2O_5 ; K_2SO_4 = ·005 grm. K_2O per 100 grms. soil.

CHART XVIII.



STATEMENT XIX.

Cyamopsis psoralioides (Guar) 1908.

Jar. No.	Jar size.	Soil per jar.	Water in soil. Per cent.	Manures.	Date of Sowing.	Date of Harvest.	Dry crop. Seed. Grms.	Dry crop. Total. Grms.	Water transpired. Kilos.	Ratio.
×	A = 9″ diam. × 12″ deep.	About 14 kilos of Pusa soil.	20	.....	Blank jars		...	...	...	...
37			20	Nil ...	11-6-08	3-12-08	7·3	24·7	27·15	1099
38			20	Nil ...	11-6-08	3-12-08	5·2	16·3	17·35	1064
39			20	N ...	11-6-08	3-12-08	3·7	10·9	9·68	888
40			20	N ...	11-6-08	3-12-08	4·5	12·9	15·62	1211
41			20	N+P ...	11-6-08	3-12-08	53·2	153·2	90·48	591
42			20	N+P ...	11-6-08	3-12-08	45·7	121·9	73·59	604

N = $Ca(NO_3)_2$ ·005 grms. N ; P superphosphate = ·01 grm. soluble P_2O_5 per 100 grms. soil.

CHART XIX.

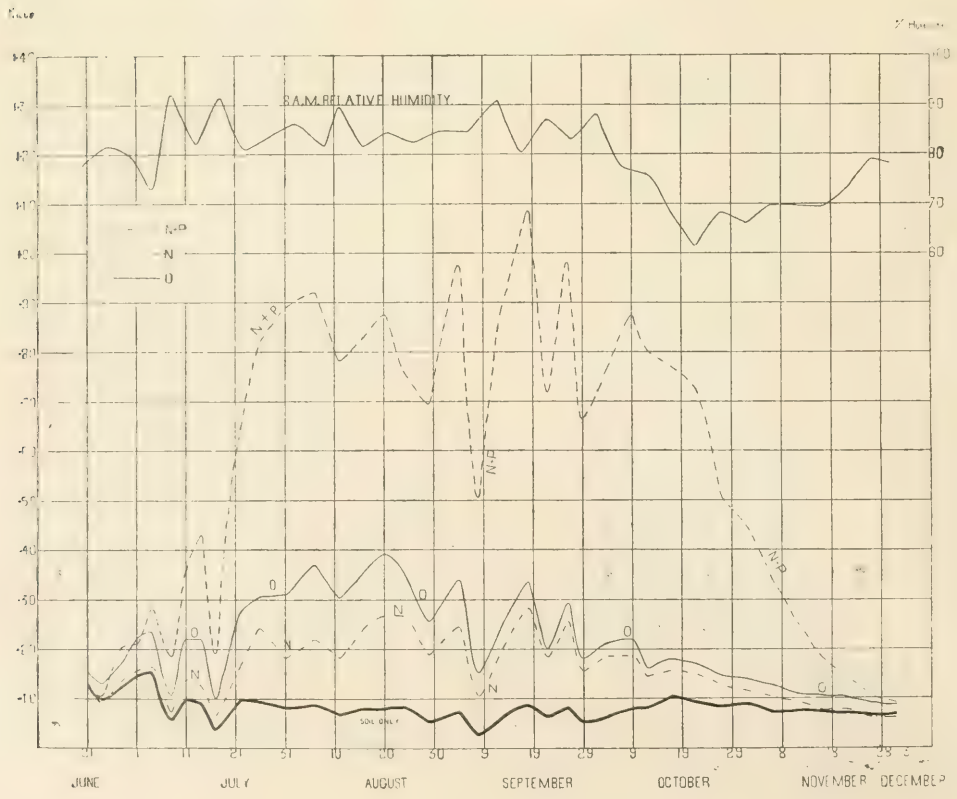
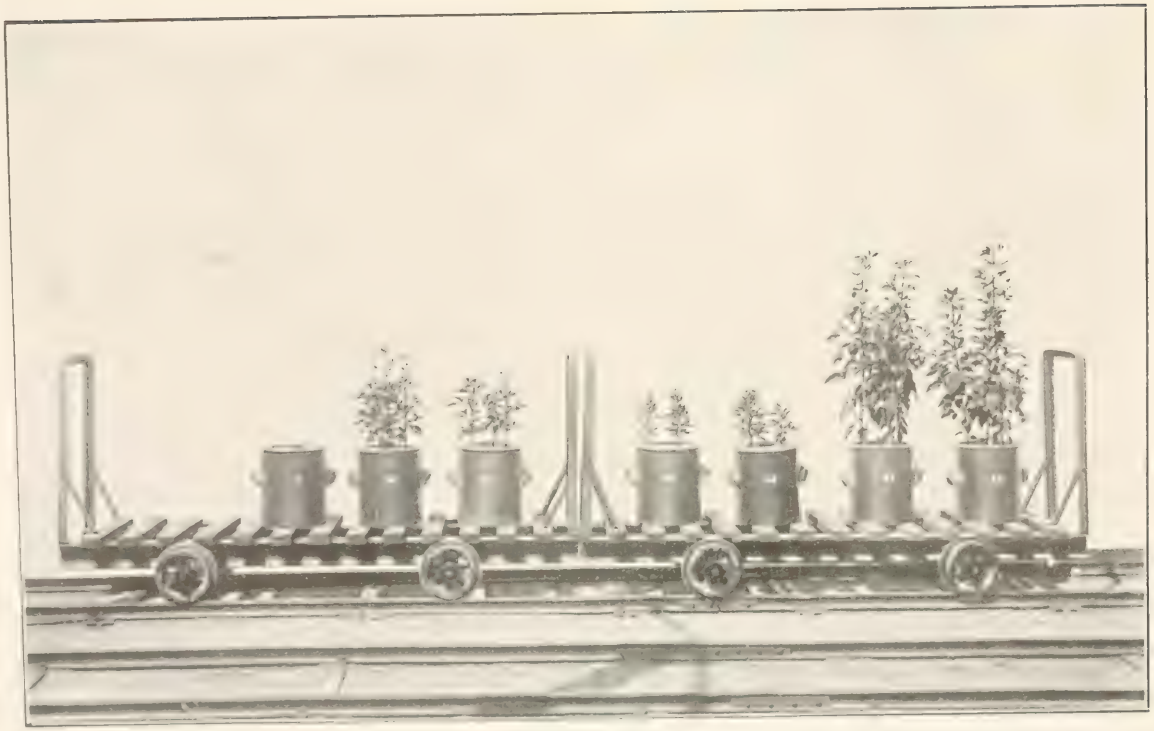


PLATE XIX.



GUAR. 1908.

37, 38 No manure.
39, 40 Nitrate only.
41, 42 Nitrate and Superphosphate.

PART III.

Deductions.

The effect of different sized jars.—Cultivation jars of different size have only been used for two of the crops, namely, wheat and maize, but this has been done during several seasons. One may anticipate therefore that any appreciable effect which this factor is liable to exert will be brought out in the series. For a complete comparison reference must be made to the statements, but it will be sufficient if the ratios obtained by the use of large and small jars of soil, unmanured, and manured with nitrate and phosphate or oil-cake and phosphate, and containing a high proportion of water, are here set out.

STATEMENT XX.

Crop.	Soil.	Manured.		Unmanured.	
		Small Jars.	Large Jars.	Small Jars.	Large Jars.
		Ratio.	Ratio.	Ratio.	Ratio.
Wheat ...	Pusa ... 1906-7	574	515	829	955
,, ...	,, 1907-8	725	605	1,133	821
Maize ...	,, 1907	382	295	604	429

This comparison shows that almost uniformly a lower ratio is obtained by the use of large jars, that is, a large mass of earth, and the same has been found quite as uniformly in other experiments. On the whole, the experience gained indicates that the use of large jars containing about 50 kilos of soil offers distinct advantages ; some plants such as maize and juar develop much more perfectly in these than in jars holding only about one-fourth the weight of soil. The effect on the ratio may be stated to be quite 10 to 20 per cent.

The effect of the proportion of water in the soil.—The experiments of the two cold weather seasons 1906-07, 1907-08 and the monsoon 1907, included soil containing materially different proportions of water. Attention has already (page 142) been directed to the fact that it is not possible to maintain a *constant*

proportion of water in the soil in pot-cultures and that indeed the amount of water transpired by vigorous plants growing in small jars occasions a very considerable diurnal variation. Among the advantages attending the use of the large jars is the maintenance of a more uniform proportion of water in the soil. We may however compare some of the ratios obtained from plants growing in soil with certain "nominally fixed" proportions of water, for if this factor controls the ratio in an important degree, it should become evident where the differences in the proportion of water are as great as those adopted.

STATEMENT XXI.

Crop.	Soil.	Manure.	Percentage of water in soil.		
			10	15	20
			Ratio.	Ratio.	Ratio.
Wheat	Pusa ...	Nil.	900	653	829
		,,	941	1,060	955
		,,	634	...	1,133
		,,	696	...	821
		Manured.	543	540	574
		,,	593	504	515
		,,	571	...	725
		,,	446	...	505
Maize	,,	No manure.	459	368	604
		Manured.	289	323	382
		Nil.	500	589	381
		Manured.	309	281	295
		Nil.	450	421	429
		Manured.	262	286	295

Of these it cannot be said that the ratio is generally, and still less uniformly, affected by the amount of water in the soil. There is on the whole a larger number of cases in which it is higher with the moister soil than the reverse. On the other hand, the development of "unmanured" plants has been very imperfect in many cases and the ratios consequently somewhat less reliable. On the whole, there is nothing in the evidence to show that the ratio is affected by this factor in so far as these experiments go. At the same time they are distinctly limited; only one soil was employed and the lowest proportion of water employed was 10 per cent. Whether the *ratio* would be affected

by lower proportions of water in this soil, and in how far it would be affected in other soils, one cannot say. As a matter of fact, we are here broaching an entirely different subject, namely, in how far water is "available" to plants in different soils. Hellriegel* made experiments on the subject in 1872 and following years, but it is far from being perfectly understood. Similarly in regard to a high proportion of water we are largely ignorant of what its effect on crops is. Hellriegel's experiments showed that a maximum development was achieved when the soil contained between 30 and 60 per cent. of that amount of water which would "saturate" the soil. Unfortunately the determination of this "saturating" proportion is not simple or accurate, and it becomes correspondingly difficult to decide what either 30 per cent. or 60 per cent. of this is.

So far as India is concerned, our chief object is naturally the determination of the *smallest*, and not the largest, amount of water which should be in a soil, and the upper limit is only of importance in cases of waterlogging.

The effect of manure —By far the most marked feature of the experiments is the effect of manure on the ratio. Confining attention for the moment to a comparison between the produce of unmanured soil and that manured with nitrate plus phosphate, a glance at the statements shows that the ratio for wheat is only about $\frac{2}{3}$ in the latter case to what it is in the former. The effect on the ratio for maize is often equally great though this is not uniformly the case. The ratios of rahar, guar, barley, oats, gram and peas were all similarly affected: the ratios for the remaining crops were decreased in the cases of manured soil, although not affected to a like degree.

As to the characteristic in the manure which is the chief agent in reducing the ratio, the majority of the data are apt perhaps to give the impression that the superphosphate has played this part. But experiments in another soil negatived this conclusion. It was a soil selected in part because the amount of

* For a complete account of Hellriegel's experiments *see* Hellriegel's Beitz. zu d. wiss. Grundlagen d. Ackerbaues, pp. 526—598

phosphate in it, as shown by Dyer's and other tests, was high, and it was anticipated that superphosphate would not increase the outturn ; an expectation which was realised. In it the best crop was obtained by the use of nitrate only, and here also the transpiration ratio was lowest. The effect of manure depends on the soil. If there is a serious deficiency of phosphate, nitrate will not increase the crop or decrease the ratio as would a mixture of nitrate and superphosphate. As regards potash, the use of sulphate of potash in the manures has in no case markedly increased the outturn, and accordingly the data do not show any change in the value of the ratio as due to this fertilizer. Speaking generally, *the effect of a suitable manure in aiding the plant to economise water* is the most important factor which has been noticed in relation to transpiration.

But one may go further than this. A comparison of the ratios obtained from duplicate jars of manured soil reveals the fact that, whenever the plants of one of the pairs of jars developed more perfectly than the other, the better development has been accompanied by a lower ratio. The magnitude of the effect has varied, but the uniformity of the result is such as to leave no doubt of the fact. The conclusion may hence be drawn that *not only manure, but good tillage, a deep soil and indeed any factor which aids in good development of the crop will tend towards an economy of water.* It presumably also explains why the ratios obtained with large jars of soil are usually distinctly smaller than with small jars, the larger quantity of soil causing a better development of plant and a consequently reduced ratio. We may properly bear this fact in mind when considering the quantities of water required by crops. Those set out on page 178 are deduced from the ratios obtained mostly in small jars of soil, and consequently the calculated quantities of water are probably rather high.

The effect of length of period of growth.—At one stage of the experiments it seemed that the length of the period between seed-time and harvest exerted a material influence on the transpiration ratios ; that indeed this increased with the length of the period.

In the following statement are set out the ratios and the length of growing period for all the crops which have been grown without respect of season.

STATEMENT XXII.

	Period. Days.	Transpiration Ratio.	
		No Manure.	Manured.
Maize	90	450	330
Murwa	100	250	250
Kodo	120	300	300
Sarson	120	740	620
Barley	120	680	480
Oats	120	870	550
Peas	120	830	530
Gram	120	1,400	1,000
Linseed	120	1,000	1,000
Wheat	150	850	550
Juar	150	400	400
Guar	170	1.100	600
Rice	180	1,000	800
Rahar	240	1.100	600

A glance over these ratios shows that in a *general* way those crops which mature rapidly have a low ratio, and the longer lived ones a high ratio ; but there are several conspicuous exceptions. Linseed and gram have much higher ratios than oats, barley, peas or sarson, all of which have the same length of growing period at the same time of the year. The linseed ratio may be somewhat high, but the plant developed very well, especially that grown in manured soil, and there seems no reason to doubt that its ratio is actually much higher than the others named. A similar remark applies to the gram. The difference between the ratios for wheat and juar, which require about equal lengths of time for maturity, may reasonably be ascribed to difference of season, because the wheat is grown during the cold weather when, the temperature is comparatively low and the humidity also low, whilst the juar enjoys the monsoon period for the greater part of the time it occupies the land, when both the temperature and humidity are a good deal higher.

The third conspicuous exception is provided by rahar (cajanus Indicus) which enjoys a total growing period very considerably longer than any of the other crops named, and has a ratio, high it is true, but not at all in proportion to its length of growth.

The general conclusion then seems to be that the length of growing period exerts either no influence on the ratio or at least only a modified one.

The nature of the crop.—The question may likewise be asked whether the nature of the crop is a factor of importance. But then what is one to understand by the term " nature of the crop." If it is interpreted as a botanical classification, then one must conclude that there is little or no connection between the natural order and the ratio. At the same time the exceptions which have been dealt with in the last paragraph tend to indicate that for each plant there is a specific ratio, which of course will be modified by the various factors surrounding the plant. In the absence of a better explanation, this seems to be the only legitimate one to offer for the markedly different ratios which have been met with. One would then lay down as a general principle that for each plant there is a specific ratio, the magnitude of which is controlled by various circumstances, and hence that the ratio for a certain crop which has not been tested, can only be prognosticated within certain wide limits.

The effect of temperature and humidity.—Experiments have frequently been made to ascertain the effect of temperature and humidity on transpiration, and the results have shown that the amount of water transpired per unit of time is increased by a rise of temperature and decreased by a rise of humidity in the air. For a more detailed account of such experiments the reader may consult " Hellriegel's Grundlagen des Ackerbaus," pp. 456 to 700, and " Burgerstein's Die Transpiration der Pflanzen," pp. 115-128. The result might indeed be anticipated on both physiological and physical grounds, for with a rise of temperature (within certain limits) the plant's energy is increased, and a rise of temperature would cause from unit surface an increased evaporation ; similarly a decreased relative humidity would aid evaporation. The experiments referred to have been, however, mostly made on plants in this connection for only short periods, whilst for our purposes the effect of the season *as a whole* is required . That humidity influences transpiration is readily shown by the daily

records ; on a wet day the quantity of water transpired decreases to say one-quarter or one-fifth of what it is on a fine day. An examination of the charts which have been reproduced in this memoir also shows it very well, for with every serious increase in humidity there is either a check in the direction of the transpiration curve or a dip in it Frequently, more especially during the initial period of growth, the daily increase in the plant's energy is so great that the effect of an increased humidity is insufficient to *decrease* the transpiration and merely checks the daily increase ; but during the later periods the amount of water transpired during wet weather falls to a very small figure. During *continuously* wet weather the protracted suspension of transpiration doubtless accounts for the yellowing of crops.

But although the effect of increased humidity on the daily transpiration is so marked, it remains to be ascertained whether the variation between one season and another is sufficient to cause a measurable difference in the total water transpired, and secondly, whether this will chiefly cause a difference in the weight of crop, or chiefly affect the transpiration ratio ?

Hellriegel sets out (pp. 664—72) a comparative analysis of temperature and humidity during three seasons at Dhame in relation to the mean transpiration ratio for barley obtained from a whole growing period ; this was 366 in a relatively warm and dry year, 1868, whereas it was 263 in a cooler and damper year, 1870. The chief data may be suitably quoted.

STATEMENT XXIII.

Year.	Mean temperature.	Mean humidity.	Ratio.
1868 ..	66	65·7	366
1870 ..	64	71	263

The difference in mean temperature is so slight that to it can hardly be attributed any large part of the difference in the quoted ratios. The chief cause of doubt that may be legitimately entertained of the soundness of his deduction, is that these ratios are in each case the arithmetical mean of a number

of ratios which varied among themselves to as great an extent as the two quoted.

The subject is best considered under two distinct sub-heads. The first relates to the difference of *plant*, the second to the difference of *season*.

As to the *plant*, reasons have already been advanced for assuming that each has probably its particular transpiration ratio. This feature of its development will no doubt be in part if not largely the outcome of its climatic surroundings, not of any one season in particular but of the many during which it has been gradually produced and to which it has become accustomed. Our monsoon crops, for instance, have enjoyed for generations a humid atmosphere, the cold-weather ones a relatively dry one. In this probably lies the explanation why the ratio of the monsoon crops is often so much below those of the cold weather.

In respect of difference of *season* it is difficult, without very considerable experience coupled with a sufficiency of suitable data, to ascertain their effect, and this is well illustrated by the following extracts from our records.

Chart No. XXIV(*a*) shows the 8 A.M. relative humidity in the upper part, and the "mean day temperature" in the lower, for the three cold weather seasons 1906-07, 1907-08, 1908-09. Chart No. XXIV(*b*) gives similar information for the two monsoon periods, 1907, 1908. Regarding the humidity, it must be admitted that the 8 o'clock record is not altogether suitable for our purpose because the relative humidity falls generally so very much as the temperature rises during the day, but an average figure is not available, and the humidity at 8 o'clock is the only record to judge by. The "mean day temperature" is the arithmetical mean between the 8 o'clock and maximum temperature. Since it is known that the greater part of the transpiration occurs during the day time, this mean figure seemed to offer a better basis of comparison than the mean temperature of the 24 hours.

An inspection of chart No. XXIV(*a*) shows that the humidity was generally higher in the season 1906-07 than in

CHART XXIV*a*.

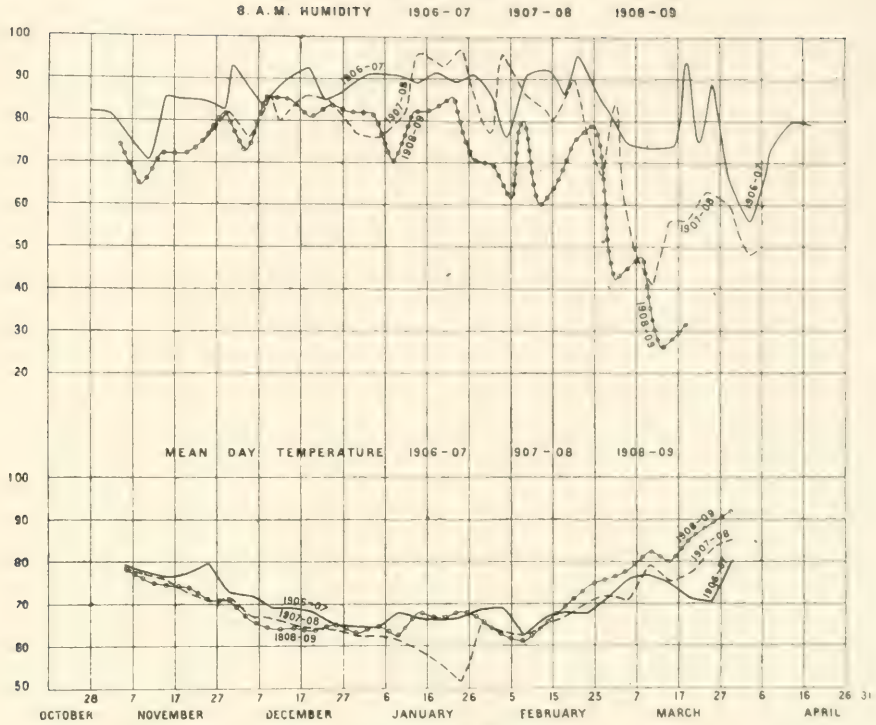
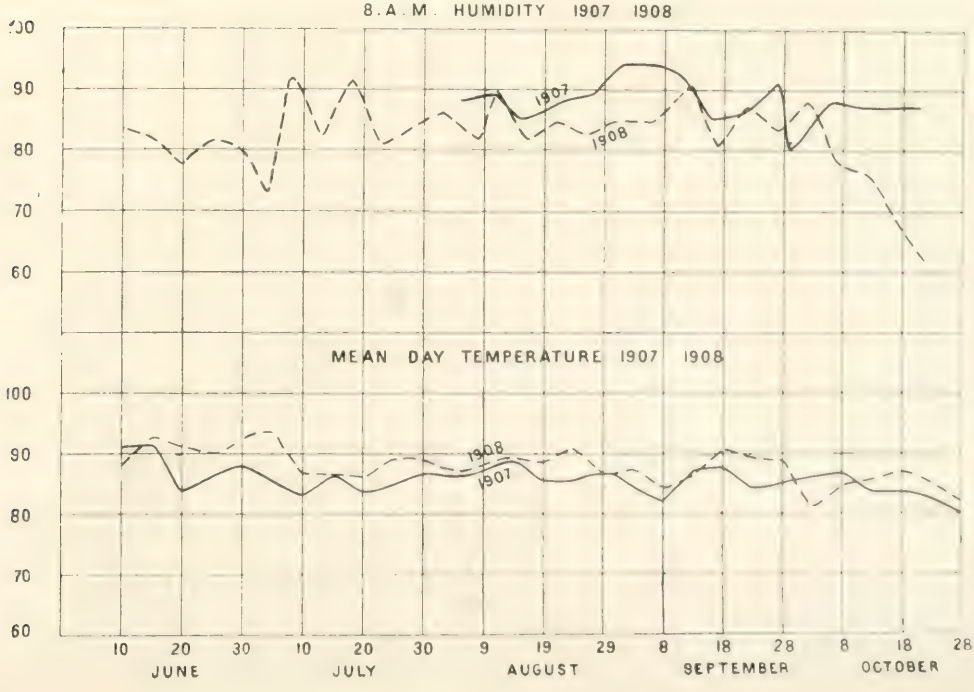


CHART XXIV*b*.



1907-08 and this again generally higher than in 1908-09; the temperatures of the three seasons were practically alike except for the cold period in January 1908 which cannot be considered likely to affect the total transpiration. If such differences in season affect the general transpiration seriously, it should have been lower in 1906-07 than in 1907-08 and highest in 1908-09. A similar examination of chart No. XXIV(*b*) shows that the monsoon of 1907 was cooler and damper than that of 1908 and the transpiration should therefore have been higher in the latter. Then will come the question as to whether the effect will be a generally increased growth or a higher transpiration ratio. As to the former there are no data; the experiments were not designed for the purpose, and there are so many factors influencing gross outturn in pot-cultures, that it is doubtful in how far these are in this respect comparable between one season and another. The effect on the *ratio* might, however, be perceptible. The data which are comparable are set out in statement No. XXIV. The ratios quoted in this are, in most cases, the means of those obtained in the experiments when the conditions were alike except for the amount of water present in the soil, which is considered to have no influence on the ratio.

STATEMENT XXIV.

	Year.	Jar size.	Manure.	Ratio.
Wheat	1906-07	A	Nil	794
		B	,,	985
	1907-08	A	,,	883
		C	,,	758
	1908-09	A	,,	865
Wheat	1906-07	A	Complete	547
		B	,,	558
	1907-08	A	,,	648
		C	,,	476
	1908-09	A	,,	507
Maize	1907	A	Nil	477
		B	,,	490
		C	,,	433
	1908	A	,,	421
Maize	1907	A	Complete	332
		B	,,	295
		C	,,	281
	1908	A	,,	433

An inspection of these data shows that the ratio for wheat was certainly not perceptibly influenced by the season, and the same remark applies to the maize grown in unmanured soil: the ratio for maize grown in manured soil was certainly lower in the cooler and damper season 1907 than in 1908. The divergence is marked, even if those for the same size of jar only are compared. Even if there had been no other evidence, too much weight would not be applicable to the ratio 433 for 1908: it is the mean of two closely coinciding ratios, but on the other hand the maize did not grow well in these small jars. There were, however, data obtained in 1908 from other experiments, to be quoted on a subsequent occasion, and if these were brought into the comparison, a somewhat lower ratio would be obtained for the 1908 season. This special reference to maize grown in manured soil is not made with the object of proving that sometimes the season affects the ratio, but rather to show how difficult it is to make a really definite deduction on this subject with the aid of only two or three seasons. Then, again, it is to be recollected that the plant itself possesses organs, such as the stomata, wax deposit, hairy growth, etc., which enable it to control transpiration.

The differences of season during the last three years have been relatively very large: the cold weather of 1906-07 was unusually wet and cool and that of 1908-09 unusually dry: there were nearly as great differences in the two monsoons: and since it has been so difficult to perceive an effect on the transpiration ratio obtained during these periods, it is legitimate to conclude that the effect of variation of season on the transpiration ratio is not large, probably not 10 per cent., but it is equally certain that one cannot make reliable deductions regarding the ratio for other parts of India. Perhaps, it would be reasonable to conclude that the ratios obtained at Pusa will be within 25 per cent. of the truth for any other part of India, in so far as climate is concerned.

The diurnal change in transpiration.—A decreased transpiration during the night period has been noticed by a number of

vegetable physiologists. A couple of extracts from our records are of interest since no others exist for India.

STATEMENT XXV.

Date.	Period.	Temperature.		Humidity.	Water lost—kilograms.				
		Hours.	Max.	Min.	8 a.m.	Maize.	Murwa.	Rahar.	Guar.	Juar.
27th July ...	Day	10	93·5	...	78	·57	·55	·65	·87	·55
28th ,, ...	Night	14	..	80·4	...	·12	·15	·16	·18	·13
28th ,, ...	Day	10	93·3	...	83	·66	·70	·81	·95	·71
29th ,, ...	Night	14	..	78·9	...	·15	·15	·19	·19	·17
						Wheat.	Barley.	Oats.	Peas.	Gram.
29th January ...	Day	10	73·7	..	69	·35	·49	·46	·80	·81
30th ,, ...	Night	14	...	41·8	.	·06	·06	·07	·16	·06
30th ,, ...	Day	10	74·5	...	65	·34	·48	·44	·90	·67
31st ,, ...	Night	14	...	39·7	...	·04	·07	·07	·18	·04
31st ,, ...	Day	10	76·7	...	64	·36	·50	·44	·94	·71
1st February ...	Night	14	..	42·2	...	08	·13	·09	·20	·10

These data illustrate the marked difference between the amounts of water transpired during the day and night respectively and at the same time show how the season also affects the process. In July, the amount transpired during 14 hours of the night is about one-fourth as much as during 10 hours of the day time; in January the relative proportion is about 1 : 8. The temperature change in July was about 15°F., in January about 30°F.

The period of greatest water requirement.—An inspection of the charts shows the period during which the major part of the water is transpired. Since the *measurable* transpiration in these jars only commences when the plant is a few inches high, it is only charted from this period, and consequently the curve does not commence until some days after sowing. It rises rapidly immediately the plant commences to "shoot" and remains high, excepting during wet weather, until very near the time of maturity, when it falls again rapidly. It is of interest to tabulate

from the curves and other data the periods during which water is most required.

STATEMENT XXVI.

Season.	First period sowing to first rapid development.	Days.	Second period during which most water is required.	Days
	Cold weather.			
Wheat 1907-08	Oct. 30th Nov. 30th	30	Nov. 30th March 29th	119
Do. 1908-09	Nov. 5th Dec. 1st	25	Dec. 1st March 28th	110
Oats	Oct. 21st ,, 4th	13	,, 4th March 4th	90
Barley	Nov. 2nd ,, 1st	28	,, 1st March 4th	94
Peas	,, 2nd Nov. 24th	20	Nov. 24th Feby. 28th	96
Gram	,, 2nd Dec. 9th	37	Dec. 9th March 9th	90
Linseed	,, 2nd ,, 4th	32	,, 4th March 9th	95
	Monsoon.			
Sarson	Oct. 20th Nov. 9th	19	Nov. 9th Jany. 31st	81
Maize 1907	July 23rd Aug. 12th	20	Aug. 12th Oct. 18th	68
Maize 1908	June 8th June 23rd	15	June 23rd Aug. 30th	86
Maize Akola soil 1908	July 4th July 20th	16	July 20th Sept. 30th	71
Maize Palur soil 1908	June 30th July 18th	18	,, 18th Sept. 26th	70
Shillong soil 1908	July 9th July 30th	21	,, 30th Sept. 27th	58
Murwa	June 9th July 9th	31	July 9th Sept. 18th	71
Kodo	June 10th July 21st	11	July 21st Oct. 12th	83
Juar	June 15th June 26th	11	June 26th Sept. 29th	95
Rice	June 10th July 11th	31	July 11th Dec. 8th	150
Guar	June 11th June 26th	15	June 26th Nov. 23rd	150
Rahar	June 11th			...

The average ratio.—From the data obtained, the following average ratios have been deduced :—

STATEMENT No. XXVII—AVERAGE RATIOS.

Crop.	Unmanured.	Manured.
Cold weather crops.		
Wheat	850	550
Barley	680	480
Oats	870	550
Linseed	1000	1000
Sarson	740	620
Peas	830	530
Gram	1400	1000
Monsoon crops.		
Maize	450	330
Juar	400	400
Murwa	250	250
Kodo	300	300
Arhar	1,000	600
Guar	1,100	600

From these rice has been excluded ; the plant grew very well, and produced a good weight of seed, but this was in less proportion to the straw than is, I think, common in the field, and the seed was smaller than normal. A more potent reason for its

exclusion lies in the fact that it was grown like "dry-land" rice and not with water on the surface of the soil. As a matter of fact, whatever the ratio for rice may be within reasonable limits, the water which its ratio represents per acre cannot bear any proportion to the total water used for wet-land paddy cultivation, and which amounts to something like 100″ or more. Regarding the other ratios, they are useful for the purpose of an approximate estimate of the amount of water required per acre.

As regards the remainder of the crops which have been brought under experiment, most of them have only been under observation for a single season. This does not in itself deduct much from the value of the ratios obtained, because in those cases where repeated tests have been made, namely, wheat and maize, the first ratios obtained have been very well substantiated by the subsequent tests. The chief element of doubt depends on the fact that they have been obtained by experiment in one soil only, and the effect of this factor remains at present an open question. They may, however, be relied on for all soils of the great alluvium.

Another point of some little importance is that they are all probably somewhat *high*. In a previous paragraph (p. 163) it has been shown that the ratio depends in part on the mass of soil in which the plant is developing, a high ratio being obtained when the quantity of soil is only small. It is probable that the ratio in the field is distinctly smaller than those quoted, but at present it is not possible to accurately estimate the difference.

The amount of water required by a crop.—That the amount of water required to grow a crop depends largely on the weight of the crop is self-evident, so that even with a knowledge of the transpiration ratio, an equally accurate knowledge of this second factor is essential in order to estimate the total requirement. It will be also readily recognised that since the outturn of crops varies within considerable limits, it becomes impossible to say how much water is required for say, "a Wheat crop" or "a Juar crop." The most one can do is to assume the position of the agriculturist who, having a knowledge of the general weight of his crops, can calculate with the aid of the transpiration ratio the

total requirement in any specified case. With this object in view the quantities which are set out in statement No. XXVIII have been calculated. It is, however, to be recollected that they are the *quantities transpired*, and do not show how much irrigation water may be needed. It has been assumed that in round numbers an "unmanured" crop (grain and straw) will weigh 1,000 lbs., that a liberally manured one will weigh 5,000 lbs. per acre. If a crop weighs more than 5,000 lbs., the same ratio may be employed as has been adopted for 5,000 lbs. without serious error. These figures may be called in question to a certain extent, especially the one for "unmanured" land, because 1,000 lbs. is certainly very small. But against this is the fact that the pot-culture grown plants in unmanured soil are much smaller than one commonly gets in the field without the aid of manure. The effect of mass of soil in controlling the ratio has been already discussed, and I am sure from certain data which we have obtained in the field, that it has its effect there just as much as in the pot-culture house. Accordingly we must assume that the ratio for unmanured crops grown in the field is not so high as the one obtained with unmanured soil in the pot-culture house. But so far as this point is concerned it is not of first importance, because clearly what we desire more particularly to know is the amount of water required for *large* crops.

If then we consider the higher ratio obtained for plants grown by pot-cultures as true for a very small field crop, and the lower one, obtained by pot-cultures with manured soil as true for a heavy field crop, and adopt intermediate ratios for crops of intermediate weight, we shall probably be as near to the truth as is at present possible. This has been done for the purpose of the estimates set out in the statement. The quantites of water are stated as tons per acre, and as inches. Rainfall is always measured in the latter manner, and irrigation water can be expressed as readily in this as in any other way. The third line of figures against each crop is the most interesting.

The two pulses Arhar and Guar require more water than the other four monsoon crops, and linseed and gram similarly

STATEMENT XXVIII.

Cold Weather Crops.

		Assumed weight of crop in lbs. per acre.				
		1,000.	2,000.	3,000.	4,000.	5,000.
Wheat	Ratio	850	775	700	625	550
	Tons per acre	378	693	940	1,120	1,220
	Inches	**3·7**	**6·8**	**9·3**	**11·0**	**12·1**
Barley	Ratio	680	630	580	530	480
	Tons per acre	304	564	778	954	1,070
	Inches	**3·0**	**5·6**	**7·7**	**9·4**	**10·5**
Oats	Ratio	870	790	710	630	550
	Tons per acre	387	712	950	1,130	1,230
	Inches	**3·8**	**7·1**	**9·4**	**11·1**	**12·1**
Linseed	Ratio	1,000	1,000	1,000	1,000	1,000
	Tons per acre	448	892	1,340	1,780	2,240
	Inches	**4·4**	**8·8**	**13·2**	**17·6**	**22·1**
Sarson	Ratio	740	710	680	650	620
	Tons per acre	330	635	911	1,160	1,380
	Inches	**3·3**	**6·3**	**9·0**	**11·5**	**13·7**
Peas	Ratio	830	750	680	600	530
	Tons per acre	370	670	913	1,070	1,180
	Inches	**3·7**	**6·6**	**9·0**	**10·6**	**11·7**
Gram	Ratio	1,400	1,300	1,200	1,100	1,000
	Tons per acre	625	1,160	1,600	1,970	2,230
	Inches	**6·2**	**11·4**	**15·8**	**19·4**	**22·0**

Monsoon Crops.

		Assumed weight of crop in lbs. per acre.				
		1,000.	2,000.	3,000.	4,000.	5,000.
Maize	Ratio	450	420	390	360	330
	Tons per acre	200	380	524	645	737
	Inches	**2·0**	**3·7**	**5·2**	**6·3**	**7·2**
Juar	Ratio	400	400	400	400	400
	Tons per acre	178	367	536	715	895
	Inches	**1·8**	**3·5**	**5·3**	**7·0**	**8·8**
Murwa	Ratio	250	250	250	250	250
	Tons per acre	112	224	336	448	560
	Inches	**1·1**	**2·2**	**3·3**	**4·4**	**5·5**
Kodo	Ratio	300	300	300	300	300
	Tons per acre	134	238	402	536	670
	Inches	**1·3**	**2·3**	**4·0**	**5·3**	**6·6**
Arhar	Ratio	1,100	970	850	720	600
	Tons per acre	491	870	1,130	1,290	1,340
	Inches	**4·9**	**8·6**	**11·2**	**12·7**	**13·2**
Juar	Ratio	1,100	970	850	720	600
	Tons per acre	491	870	1,130	1,290	1,340
	Inches	**4·9**	**8·6**	**11·2**	**12·7**	**13·2**

a good deal more than the other cold weather crops. But what is still more striking is the fact that, broadly speaking, the cold weather crops transpire a good deal more water than those of the monsoon season. Since it is generally recognised that more rain is required during the monsoon period than the cold weather, the practical agriculturist may be inclined to doubt the correctness of the estimates, but apart from the fact that there is no legitimate reason for doubting the ratio obtained by pot-cultures to a greater extent than has been already suggested, there are several agricultural features *apart from the crop* which will readily account for the greater water requirement of the monsoon period. In the first place, it must be recollected that, at the end of the hot weather, the upper soil is so desiccated that a very considerable amount of rain is required before any crop can be expected to grow. Then too the amount of water lost by direct evaporation from the land during the monsoon must be for most soils greater than during the dry weather. The reason for this is simply that a larger amount of water is quite near the surface of the soil during wet weather than later on, when the upper foot or two feet are partly dry. A proof of this statement is also provided by the Rothamsted drain-gauge data which show that evaporation is greater in a wet year than in a dry one. Again, when considering the effect of humidity on transpiration, the small ratio of the monsoon crops, Maize, Juar, Ragi, Kodo in comparison with the others has been shown to be probably attributable to the nature of the crop, which has for generations become accustomed to growth in the more humid atmosphere of the monsoon period. Finally, in so far as a necessity for an abundant monsoon rainfall is concerned, it is to be recollected that one of its important functions in Upper India is the provision of a thoroughly damp soil for the succeeding cold weather crops. There are thus several reasons for experiencing no surprise that some at least of the rains crops require comparatively little water for *transpiration* purposes. The cold weather crops, on the other hand, develop in a comparatively dry atmosphere, which would naturally tend to cause a more vigorous transpiration.

In conclusion, reference may be made to the influence which the soil has on this subject. In some places where the soil is only a couple of feet thick, as in parts of the Deccan, quantities of irrigation water which are far in excess of those set out in the statement No. XXVIII are known by practice to be necessary; in other places, one or two irrigations, say 2″—4″ is sufficient to produce heavy cold weather crops; again, in Behar much of the soil is capable, provided it has been fallow during the monsoon, of producing, with the aid of manure but without rain or irrigation, very heavy crops. During the past cold weather for instance, such crops were produced, after a weak monsoon, with only ·38″ of rain during the cold weather. I am sure this aspect of the subject will be readily appreciated. It is indeed not only a question of how much water crops transpire, but also to what extent a soil acts as a ready reservoir of water. That soils vary in this respect was shown by Hellriegel, but it is doubtful whether its full significance has been generally appreciated. Whilst large cold weather crops could be grown in the soil at Pusa without any rain, the soil at Cawnpore, also liberally manured, could only produce very moderate ones; and yet the difference in the initial amount of water in the upper soil in the two places was only nominal. The quantities of water mentioned in the statement as being necessary for the transpiration requirements of cold weather crops probably provide an index of the maximum water which might have to be given either as rain or irrigation water in the great alluvium, but in how far the water which is in the soil at the conclusion of the monsoon assists the plant and so reduces the amount of irrigation water or rain required, must depend on the nature of the soil itself. The root range is naturally of importance and more information regarding it is required, and the capability of a soil to "yield" its water to plant roots is of equal importance.

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